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# **EVALUATION OF REPLACEMENT THREAD LUBRICANTS FOR RED LEAD AND GRAPHITE IN MINERAL OIL**

**WPAD-QES-ME-1206**

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## ABSTRACT

Eight commercially available thread lubricants were evaluated to determine the best replacement for Red Lead and Graphite in Mineral Oil (RLGMO). The evaluation included coefficient of friction testing, high temperature anti-seizing testing, room temperature anti-galling testing, chemical analysis for detrimental impurities, corrosion testing, off-gas testing, and a review of health and environmental factors. The coefficient of friction testing covered a wide variety of factors including stud, nut, and washer materials; sizes, manufacturing methods, surface coatings, surface finishes, applied loads, run-in cycles, and relubrication. Only one lubricant, Dow Corning Molykote P37, met all the criteria established for a replacement lubricant. It has a coefficient of friction range similar to RLGMO. Therefore, it can be substituted directly for RLGMO without changing the currently specified fastener torque values for the sizes, materials and conditions evaluated. Other lubricants did not perform as well as Molykote P37 in one or more test or evaluation categories.

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## **Evaluation of Replacement Thread Lubricants For Red Lead And Graphite in Mineral Oil**

### **I. Introduction**

Westinghouse uses hundreds of bolted closures on power plants, employing fastener materials including high-strength alloy steels, nickel-based alloys, copper-nickel, austenitic stainless steels and aluminum alloys. Since many of these fasteners rely on torque to establish precise preload stresses in the bolted closure, the thread lubricant must be well characterized with a predictable and narrow coefficient of friction range. For closures in some high temperature systems the purity of the lubricant is essential. The lubricant must contain very low levels of detrimental materials, such as mercury, sulfur, phosphorus, halogens and low melting points metals. Also, in high-temperature systems the lubricant must possess adequate anti-seizing properties to permit disassembly and maintenance of the hardware.

Other characteristics of concern relate to the health and environmental aspects of the lubricant. Lubricants are used in confined spaces; therefore, they must have minimal toxicity to the workers both during initial application and at elevated temperatures where volatile toxic gases may be produced. Lubricants that are considered environmentally hazardous will result in additional disposal cost at the end of life.

### **II. Background**

For more than 20 years Westinghouse has specified the use of Red Lead and Graphite in Mineral Oil (RLGMO) per the Military Specification MIL-L-24479 as a thread lubricant for fastener applications, including closure fasteners on high-pressure and high-temperature components. Many of these fasteners rely on torque to establish precise preload stresses. RLGMO has provided a predictable and narrow coefficient of friction range, resulting in excellent performance. Based on testing with a limited number of fastener alloys, the design coefficient of friction range of RLGMO was established to be from 0.05 to 0.11. This range has proven to be narrow enough so that a single torque value can be assigned to a fastener design. Based on analysis, a single torque value can produce an installation load will not exceed the design stress limits on the fastener while achieving the necessary preload for operation.

However, concerns regarding the hazardous nature of lead both to the worker and for eventual disposal of hardware, as well as more restrictive environmental regulations regarding the use of lead, prompted Westinghouse to evaluate, qualify, and prepare a specification for the procurement of a non-hazardous commercial lubricant as a replacement for RLGMO. As a secondary objective, Westinghouse evaluated if the replacement lubricant could also replace a second widely used thread lubricant, Molybdenum DiSulfide in Isopropanol (MDSI). MDSI is used interchangeably with RLGMO on many alloy steel fasteners as well as in high temperature applications on nickel-based alloys.

### **Objectives**

The objective of the original phase of testing was to evaluate and identify a non-hazardous commercial lubricant to replace RLGMO, possessing a coefficient of friction range which duplicates that of RLGMO. The objective of the second phase of testing was to expand the coefficient of friction database for the selected lubricant with additional alloy combinations, fastener sizes and manufacturing methods. This report summarizes the process used to select the replacement lubricant and provides the coefficient of friction data for use with this lubricant.

### **Overall Approach**

Based on a review of product literature and material safety data sheets (MSDS) for 14 commercially available anti-seizing lubricants, eight candidate lubricants that did not contain obvious detrimental materials were selected for testing as potential replacements. These lubricants fell into three broad categories based on their anti-seize additives: nickel-based, copper-based or metallic-free. In addition to the eight candidate lubricants, both RLGMO and MDSI were included in the test plan to act as controls and provide comparisons to current experience.

In order to select a suitable replacement for RLGMO and MDSI, the following characteristics (acceptance criteria) were evaluated:

- ▶ Coefficient of friction range (similar to the established range for RLGMO, that is, 0.05 to 0.11).
- ▶ Anti-seizing capability (preclude seizing after service at temperatures up to 650°F).
- ▶ Anti-galling capability (preclude galling of fasteners at ambient temperature during initial torquing).
- ▶ Detrimental material content (less than 250 parts per million (ppm) of low melting point metals, halides, sulfur, and phosphorus and less than 10 ppm of mercury).
- ▶ Health related concerns (minimal worker safety precautions required and no release of toxic gases during heating).
- ▶ Environmental concerns (that is, it is not a hazardous material relative to disposal).
- ▶ Corrosivity (that is, it will not cause general or localized corrosion or exacerbate stress induced corrosion of the fastener or adjacent materials).

After this evaluation had been completed and the replacement lubricant determined, additional coefficient of friction testing was conducted to expand the database to a number of prototypic fastener combinations.

### **III. Experimental Procedures**

#### **Candidate Lubricants**

A compositional summary of the 10 lubricants evaluated is given in Table 1. The compositions listed were based on manufacturer's literature as well as the corresponding MSDS.

Table 1 Test Lubricants and Qualitative Composition

| LUBRICANT |  | COMPOSITION, PERCENT |        |          |   |
|-----------|--|----------------------|--------|----------|---|
| No.       | Manufacturer, Name                                       | Copper               | Nickel | Graphite | Other   |
| 1         | Fel Pro, N5000, High Performance                         |                      | 20     | 25       |   |
| 2         | Fel Pro, N1000   | 20                   |        | 25       |   |
| 3         | Huron, Neolube No. 650                                   |                      |        | 40-60    | 25-50 Mineral Oil<br>2-25 Petrolatum                                    |
| 4         | Jet Lube, NIKAL, Nuclear Grade                           |                      | 30     |          | Polyisobutene   |
| 5         | Fel Pro, N2000, High Purity                              | 25                   |        | 20       | 25 Petroleum Distillates  |
| 6         | Bostik, Never Seez - Ni/Nuclear Grade                    |                      | 18     |          | Talc<br>Bentone Grease  |
| 7         | Lub-O-Seal, NM-91 Anti-Seize, Nuclear Grade              |                      |        | unknown  |   |
| 8         | Dow Corning, Molykote P37 Paste                          |                      |        | 21       | 50 Mineral Oil<br>14 Calcium Hydroxide<br>9 Zirconium Oxide<br>1 Silica |
| 9         | Molybdenum Disulfide in Isopropanol (MDSI) MIL-L-24478   |                      |        |          | 60 Molybdenum Disulfide<br>40 Isopropanol                               |
| 10        | Red Lead and Graphite in Mineral Oil (RLGMO) MIL-L-24479 |                      |        | 16       | 60 Lead Oxide<br>24 Mineral Oil   |
|           | Fel Pro, N7000 (Phase II testing only)                   |                      |        | 20       | 25 Calcium Oxide  |

### Functional Testing

A test program was developed to evaluate each lubricant's coefficient of friction, anti-seizing, and anti-galling capability. This testing was designed to provide a statistically significant database on all ten lubricants so that comparisons could be made between the candidate lubricants, RLGMO and MDSI. These comparisons of performance would form the basis for the best replacement for RLGMO and possibly MDSI. For the evaluation of anti-galling and anti-seizing resistance three material combinations were used: Type 304 (Unified Numbering System (UNS) S30400) stainless steel studs and nuts, alloy steel (AISI 4140 - Grade B7 (UNS G41400)) studs and carbon steel (UNS K04002) nuts and Monel K-500 (UNS N05500) studs with Monel 400 (UNS N04400) nuts. The stainless steel combination was judged most likely to result in galling for a poor or marginal lubricant. These combinations allow the evaluation of actual fastener materials

as well as assuring test "failures", so that the candidate lubricants can be ranked. Due to the relatively low usage of stainless steel fasteners in actual hardware, Alloy 625 (Inconel 625 - UNS N06625) studs and nuts replaced the stainless steel combination in the coefficient of friction testing. This phase of testing also included the K-500/Monel 400 combination as well as both bare and phosphate coated alloy steel studs. The studs were 3/4-10UNC-2A with rolled threads. For the above combinations, hardened carbon steel washers were used to represent a prototypical bearing surface. The washers were fixed so they could not rotate during the test which could have resulted in erroneous coefficient of friction values. For each test a new (previously unused) stud, nut, and washer were employed.

Prior to testing, the studs, nuts, and washers were cleaned in sequential baths of trichloroethane and acetone and dried. Studs were visually inspected for burrs and defects which could lead to premature galling during the tests. Studs and nuts were assembled by hand to ensure that there was no interference or binding prior to testing. Each test assembly and its individual components were engraved with a unique identification number representing the alloy, the lubricant, and the test set number.

### Coefficient of Friction Testing

#### Phase I Testing

Two Skidmore-Wilhelm Torque Tension units equipped with calibrated load cells, shown in Figure 1, were utilized for measuring the load on the test assembly. Typical test assemblies are shown in Figure 2. For each material/lubricant combination, five duplicate test assemblies were loaded in five equal increments up to a load value equivalent to 2/3 of the stud material minimum yield strength. At each increment the torque value was recorded. Each loading cycle was repeated four times. The four loading cycles were defined as follows:

|                               |  |
|-------------------------------|--|
| Cycle A<br>(Run-In) .         | Representing a new, unused fastener torqued for the first time.  |
| Cycle B<br>(Design)           | Representing a fastener having been subjected to a previous torquing cycle, disassembled, additional lubricant applied and retorqued. This generally represents actual fastener installation practice, and is considered most prototypical.    |
| Cycle C<br>(Used Stud Run-In) | Representing a used fastener that has been removed from the original hardware, cleaned, relubricated and retorqued.  |
| Cycle D<br>(Used Stud Design) | Representing a used fastener that has been removed from the original hardware, cleaned, relubricated, retorqued once, disassembled additional lubricant applied and retorqued again, that is, a used fastener subjected to Cycle B conditions. |

Between Cycles A and B, and Cycles C and D, the nuts were run back far enough to add additional lubricant, and the assembly was retorqued in the same five-step sequence as the previous cycle. This was done to simulate the installation procedure currently in use. A complete cleaning of the assembly was performed between Cycles B and C to simulate a maintenance event during the life of the component. During the maintenance event the stud is removed, cleaned and reinstalled. Therefore, Cycle D represents the typical coefficients of friction seen during the installation of a "used stud."

The torque wrenches and the Skidmore-Wilhelm torque-tension test units were calibrated prior to and at the completion of testing. The calibrations were factored directly into the equation used to calculate the coefficient of friction values. In addition to the initial calibration, the torque wrenches also received a daily calibration at the highest torque value expected during that day's tests. The accuracy of the torque wrenches was  $\pm 2$  percent.

### Phase II Testing

After the completion of the initial program described above and selection of Molykote P37 as the replacement lubricant, a follow-up program was designed to establish coefficient of friction ranges for additional fastener parameters. The test sequence was a simplified version of the Phase I testing and was defined as:

- |                     |   |
|---------------------|---|
| Cycle 1<br>(Run-In) | Representing a new, unused fastener torqued for the first time.   |
| Cycle 2<br>(Design) | Representing a fastener having been subjected to a previous torquing cycle, disassembled, additional lubricant applied and retorqued. This generally represents actual fastener installation practice, and is considered most prototypical. |
| Cycle 3<br>(Design) | Representing a duplicate of the Cycle 2 loading step to increase the available data.  |

This simplified sequence was selected since the data from Cycles B and D in the initial phase were unaffected by Cycle C. This testing was designed to evaluate:

- ▶ additional fastener (stud and nut) material combinations
- ▶ different size fasteners - 3/4 to 2 inches in diameter
- ▶ different bearing (washer) materials
- ▶ different manufacturing methods - machined and rolled threads
- ▶ a new metallic-free lubricant as a potential alternate to Molykote P37

The additional fastener materials included K-500 studs with K-500 nuts, titanium (UNS R56401) studs with Alloy 625 nuts, Type 17-4PH (UNS S17400) studs with Type 316 (UNS S31600) stainless steel nuts. The detailed listing of materials, sizes and surface treatments are listed in Table 7. Except as noted in the following list, five duplicate assemblies were used for each lubricant tested. The following exceptions to the five assemblies were:

- ▶ Due to cost considerations, only one assembly was provided for testing of RLGMO, for the four machined Alloy 625 sets which ranged in size from 0.75, 1.75 and 2.0 inches in diameter.
- ▶ Four Type 17-4PH/Type 316 test assemblies used a Type 316 washer, while the fifth set was tested with a carbon steel washer to investigate the effect of the bearing material.
- ▶ Two K-500/K-500 assemblies were tested with each of the following washer materials for comparison to those tested with carbon steel washers: HY-80 (UNS J42015), Type 430 (UNS S43000) stainless steel, and Alloy 625.

### Anti-Seizing Testing

The high temperature anti-seizing test required exposing test assemblies, consisting of a stud with two nuts torqued to a load representing 2/3 of the yield strength of the stud material, to a temperature of 650°F. For each lubricant/material combination, one test assembly was removed

from the test oven at time intervals of one, three and six weeks. The final two test assemblies were removed after ten weeks. After each test assembly was removed from the oven, it was disassembled, inspected for the condition of the residual lubricant, cleaned and inspected for signs of material degradation, such as pitting or general corrosion. The installation and breakaway torque values were recorded for each cycle.

### **Anti-Galling Testing**

For each material and lubricant combination, two test assemblies were subjected to up to twelve torquing and untorquing cycles. For each new test assembly, lubricant was applied to the stud and nut threads as well as the nut and washer bearing surfaces. After the fourth and eighth cycle the assembly was removed and cleaned of residual lubricant, reassembled and fresh lubricant was applied. For the first eight cycles, the assemblies were loaded to 2/3 of the minimum yield strength of the stud material. For the final four cycles, the assemblies were loaded to the minimum yield strength value. The installation and breakaway torque values were recorded for each cycle and any occurrence of galling was recorded. Because the assemblies were only relubricated after the fourth and eighth cycles, the probability of galling was enhanced. After the completion of the testing, each assembly was visually inspected at 15 to 20X magnification for evidence of galling. For each of the three alloy combinations, an initial test assembly was tested without lubricant to demonstrate that galling would occur.

### **Detrimental Material Evaluation**

A sample of each candidate lubricant in its original container was evaluated for the following detrimental materials: mercury, antimony, bismuth, cadmium, lead, tin, zinc, sulfur, and phosphorus, and the following halides: chloride, bromide, and fluoride.

### **Health and Environmental Testing**

Although details are beyond the scope of this paper, the following actions were taken for each candidate lubricant in order to assess the health and environmental issues:

- ▶ Off-gas testing was performed to determine if toxic gases would be released at 650°F.
- ▶ A hazardous material review was conducted in accordance with 40 CFR Part 261.
- ▶ A toxicological evaluation in accordance with the guidelines established by the International Agency for Research on Cancer (IARC), the American Conference of Governmental Industrial Hygienists (ACGIH) and the Environmental Protection Agency (EPA) was performed.

### **Corrosion Testing**

The eight candidate replacement lubricants, MDSI, and RLGMO were applied to seven groups of representative fastener alloys, as listed in Table 2. The fastener assemblies were 3/4-10UNC studs and nuts.

**Table 2 Corrosion Test Alloy Combinations**

| STUD MATERIAL                                 | NUT MATERIAL                                |
|---|---|
| Steel, AISI 4140<br>Grade B7 (UNS G41400)     | Steel<br>ASTM A194, Grade 4                 |
| Type 304 Stainless steel<br>(UNS S30400)      | Type 304 Stainless steel                    |
| 70/30 Copper Nickel<br>(UNS C71500)           | 70/30 Copper Nickel<br>(UNS C71500)         |
| Nickel Aluminum Bronze<br>(UNS C63200)        | Nickel Aluminum Bronze<br>(UNS C63200)      |
| Monel K-500 (UNS N05500)<br>QQ-N-286, Class A | Monel 400 (UNS N04400)<br>QQ-N-281, Class A |
| Alloy 625 (UNS N06625)<br>ASTM B446, Grade 1  | Alloy 625<br>ASTM B446, Grade 1             |
| Titanium (UNS R50400)<br>ASTM B348, Grade 2   | Titanium<br>ASTM B348, Grade 2              |

The corrosion test program consisted of four categories of tests, which are summarized as follows:

**Test 1 - Localized Fastener Corrosion Due To Lubricant In Air**

In this test, studs and nuts of each fastener alloy were lubricated with one of the ten original lubricants. Four nuts of the corresponding alloy were assembled on each lubricated stud to provide the test specimen. Some nut faces were coated with lubricant and some were cleaned of lubricant. The test specimen therefore contained lubricant filled crevices, lubricant covered noncreviced surfaces and clean noncreviced surfaces. The test specimens were placed in an oven with an air atmosphere at a temperature of  $250^{\circ}\text{F} \pm 10^{\circ}\text{F}$  and held for 750 hours. The test specimens were then cleaned and visually examined to establish whether any surfaces covered by the lubricant were more heavily corroded than surfaces cleaned of lubricant.

**Test 2 - Localized Fastener Corrosion Due To Lubricant In Salt Water**

In this test, studs and nuts of each fastener alloy were lubricated with each of the ten original lubricants. Four nuts of the corresponding alloy were assembled on each lubricated stud to provide the test specimen. Some nut faces were coated with lubricant and some were cleaned of lubricant. The test specimen therefore contained lubricant filled crevices, lubricant covered noncreviced surfaces and clean noncreviced surfaces. Unlubricated control test specimens of each fastener alloy were also prepared. The test specimens were placed in a synthetic salt water test solution, heated to a temperature of  $175^{\circ}\text{F} \pm 5^{\circ}\text{F}$  and held for 750 hours. A separate test solution was used for each test specimen. The test specimens were then cleaned and visually examined to establish whether any lubricated test specimen was more heavily corroded than the unlubricated control specimen of the same fastener alloy.

**Test 3 - Environmentally Induced Corrosion Due To Lubricant In Salt Water Or In Distilled Water**

In this test, studs and nuts of each fastener alloy were lubricated with each of the ten original lubricants. Some of the lubricated studs and nuts were placed in an oven at approximately  $650^{\circ}\text{F}$  for several hours to volatilize the lubricant. Two nuts of the corresponding alloy were assembled

on each stud. A spacer, fabricated from a nut of the corresponding alloy, was installed between the two nuts. The stud was then placed in a tensile test machine and loaded to 90 percent of the stud yield strength reported in the certified material test report. The two nuts were hand tightened against the spacer and the applied load was then released to provide the test specimen. Unlubricated control test specimens of each fastener alloy were also prepared.

For each lubricant and for each fastener alloy, sets of three test specimens were prepared consisting of one lubricated test specimen (as-lubricated), one test specimen made with lubricated and volatilized studs and nuts (volatilized), and one unlubricated test specimen (unlubricated). One set of test specimens was placed in a common synthetic salt water test solution, and one set of test specimens was placed in a common distilled water test solution. One unlubricated control test specimen for each fastener alloy was also tested in a separate salt water test solution and one in a separate distilled water test solution. The test solutions were heated to a minimum of 170°F and allowed to evaporate off water vapor so that the test solutions evaporated in approximately 150 hours.

The test specimens were then cleaned and examined visually and by fluorescent penetrant inspection to establish whether a test specimen in the set for any lubricant showed defects that were not found in the unlubricated control specimen of the same fastener alloy tested in the same medium. Studs were fluorescent-penetrant inspected prior to testing to identify defects that could interfere with the post-test inspection. Studs with defects were excluded from testing where possible.

#### Test 4 - Galvanically Assisted Localized Corrosion

In this test 3/4-10UNC studs of titanium alloy Grade 2 and carbon steel nuts were lubricated with each of the 10 original lubricants. Some of the lubricated studs and nuts were placed in an oven at approximately 650°F for several hours to volatilize the lubricant. One nut was assembled on each stud to provide the test specimen. Unlubricated control test specimens were also prepared.

In one series of tests, one test specimen for each lubricant and one unlubricated control test specimen was placed in an oven with an air atmosphere at a temperature of 250°F  $\pm$  10°F and held for 750 hours. The test specimens were then cleaned and visually examined to establish whether any surfaces covered by the lubricant were more heavily corroded than the unlubricated control specimens.

In a second series of tests, one lubricated test specimen and one test specimen made with lubricated and baked studs and nuts were placed in a distilled water test solution. One unlubricated control test specimen was also tested. A separate test solution was used for each test specimen.

The test solutions were heated to a temperature of 175°F  $\pm$  5°F and held for 750 hours. The test specimens were then cleaned and visually examined to establish whether any lubricated test specimen was more heavily corroded than the unlubricated control specimen.

## IV. Results And Discussion

### Coefficient of Friction Results

The coefficients of friction for each torque increment was calculated using the relationship shown in Appendix A. Various summary statistics were performed on the coefficient of friction data. A discussion of the statistics and the coefficient of friction results are included in Appendix B. These statistics were focused in five basic categories; the tolerance range of the data, form of the distribution of individual values, stud-to-stud variations, significant differences between run-in and design values and the significant differences between the design value and the used stud design value. The importance of the coefficient of friction on design is mainly the ability to accurately predict the stress in a loaded stud/fastener. A small range of the coefficient of friction is essential and is considered to be the best measure of the relative merit (from a coefficient of friction viewpoint) of lubricant candidates. A 90/95 tolerance interval (90 percent confidence that 95 percent of the data falls within the interval) was chosen to rank the lubricant candidates and the control lubricants.

The tolerance ranges for each lubricant/material combination have been calculated and are provided in Attachments I-IV of Appendix B. These are 90/95 tolerance ranges and the relative merit of each lubricant is shown in Figure 3 for the design and used stud design values of measured coefficient of friction. These results demonstrate that Molykote P37 is very similar in performance to RLGMO based on the mean coefficient of friction and the tolerance range.

### Phase I Test Results

The individual ranges for each lubricant are graphically presented in Figures 2 and 3 of Appendix B. Based on the evaluation of the test data, Molykote P37 can be used in place of RLGMO or MDSI with no adjustment to the specified torque values determined for RLGMO and MDSI, because of the similarity in coefficient of friction range. The overall 90/95 tolerance ranges of coefficient of friction, inclusive of the four material combinations tested, for the replacement and the control lubricants are listed in Table 3.

**Table 3      Coefficient of Friction Ranges (90/95 Tolerance Interval)**

| LUBRICANT                      | COEFFICIENT OF FRICTION RANGE |                   |
|--------------------------------|-------------------------------|-------------------|
|                                | Westinghouse Testing          | Established Range |
| Dow Corning Molykote P37 Paste | 0.06 - 0.16                   | ----              |
| RLGMO                          | 0.06 - 0.15                   | 0.05 - 0.11       |
| MDSI                           | 0.05 - 0.26                   | 0.05 - 0.14       |

Although the ranges for the replacement lubricants appear to be significantly larger than the established range listed for RLGMO, the results of the Westinghouse testing actually produced a RLGMO range of 0.06 to 0.15 which is comparable to the range for Molykote P37. The range for MDSI is significantly wider than the replacement. The basis for the difference between the Westinghouse results and the established range is that Westinghouse data have been skewed to the high end by the inclusion of unplated Alloy 625 fasteners in the testing. The previously

established ranges for coefficient of friction were based on test data from a limited number of alloys, primarily alloy steels. Nickel-chromium-iron based alloy fasteners were not included in previous testing. Using the data of Tables XI and XIII of Appendix B, the ranges listed in Table 4 have been calculated without Alloy 625 data included.

**Table 4      Coefficient of Friction Range (excluding Alloy 625)**

| LUBRICANT                      | COEFFICIENT OF FRICTION RANGE<br>(excluding Alloy 625) |                      |
|--------------------------------|--|----------------------|
|                                | Westinghouse<br>Testing                                | Established<br>Range |
| Dow Corning Molykote P37 Paste | 0.07 - 0.12  | ---                  |
| RLGMO                          | 0.06 - 0.13  | 0.05 - 0.11          |
| MDSI                           | 0.05 - 0.13  | 0.05 - 0.14          |

Several conclusions can be drawn from these data. First, the coefficient of friction ranges for RLGMO and Molykote P37 continue to be consistent with each other, having the same arithmetic average, and the Molykote P37 range is within the MDSI range. Second, the RLGMO and MDSI ranges found in the Westinghouse testing match well with the established ranges when unplated Alloy 625 fasteners are excluded. Finally, it is technically feasible to develop separate coefficient of friction ranges for unplated Alloy 625, which can allow for tighter control on design torques. Based on the test results and the comparison to the currently acceptable ranges, two coefficient of friction ranges for Molykote P37 were established. The standard range, 0.07 - 0.12, will be that which excludes the Alloy 625 results, since this range is directly comparable to the current ranges used for RLGMO and MDSI. It should be noted that this range has been developed using 3/4-inch fasteners of uncoated and phosphate coated alloy steel, alloy steel nuts, and steel washers, as well as Monel K-500 studs with Monel 400 nuts and steel washers. The vast majority of fasteners in service are either alloy steel or Monel K-500, both of which have been included in the Westinghouse testing. The Phase II testing was initiated to evaluate other fastener materials against these ranges. In addition, a second range was established that is specific to unplated nickel-chromium-iron-based alloy fasteners based on the Alloy 625 test data. This range of coefficient of friction is 0.06 - 0.16 for Molykote P37.

#### Phase II Test Results

As with the coefficient of friction data generated in the original (Phase I) program, various summary statistics were performed on the data. These statistics included the tolerance range of the data, significant differences between run-in (Cycle 1) and design values (Cycle 2) and the significant differences between the design value and the used stud design value (Cycle 3). The actual coefficient of friction results for all Phase II tests are provided in Appendix C. A summary of the mean, standard deviation and 90/95 tolerance range of the coefficient of friction results for Molykote P37 and RLGMO is provided in Table 5 for the run-in cycle and Table 6 for the design cycles, that is, combined coefficient of friction values for Cycles B and D for Phase I and Cycles 2 and 3 for Phase II. For alloy combinations that included less than four test assemblies, only the mean and standard deviation is reported. The data in Tables 5 and 6 are grouped by the composition of the test stud. The results reported in Tables 5 and 6 are considered worst case, that is, skewed to the high side of the coefficient of friction range, since the fasteners have been procured as off-the-shelf items. The only exception to this are the four sets of Alloy 625

assemblies, beginning with the label 'IM' and the alloy steel assemblies labeled 'AS', which are actual production hardware.

Comparison of the design (Cycle 2) coefficient of friction values from the Phase II tests supports the substitution of Molykote P37 for RLGMO. This is especially true for the alloy steel and Alloy 625 materials. The most significant difference between Molykote P37 and RLGMO is observed for the largest diameter fasteners. For sizes up to 1.75 inches in diameter the difference between the Molykote P37 and RLGMO coefficients of friction is less than or equal to 0.02; however, for the 2.0 inch Alloy 625 fastener combination the mean coefficient of friction for Molykote P37 exceeds that of RLGMO by more than 0.05 for the run-in cycle and 0.02 for the subsequent cycles. For fastener sizes larger than 1.5 inches, which rely on torque to establish the preload, the use of a run-in cycle and prototypic testing should be strongly considered.

The other instance in which a significant difference between lubricants was observed occurred for the Type 17-4PH stud with a Type 316 nut bearing on a Type 316 stainless steel washer. For this material combination the coefficient of friction range more closely matched that originally established for Alloy 625 fasteners. When a carbon steel washer was substituted for the stainless steel washer the coefficient of friction values began to converge.

The following summarizes the results observed for each alloy family tested and for the various fastener parameters evaluated:

- |                    |  |
|--------------------|--|
| <b>Alloy Steel</b> | The coefficient of friction data for all alloy steel combinations were essentially the same and within the range of the previous testing. The only exception is for Molykote P37 on the larger, 1.5-inch diameter fasteners, which exhibited a Cycle 2 mean coefficient of friction of 0.12 and a tolerance range of 0.10 to 0.14. This is compared to an equivalent range of 0.10 to 0.12 for the RLGMO. It should be noted that for the run-in cycle the mean and tolerance range for both lubricants are essentially the same. Examination of the data indicates that for Cycles 1 through 3 as well as for each load increment, the coefficients of friction for RLGMO are essentially the same while for Molykote P37 the values for Cycles 2 and 3 increase slightly. This observation is contrary to the general trend that the coefficient of friction tends to decrease with subsequent cycles.   |
| <b>Monel K-500</b> | As observed in the original testing, Molykote P37 consistently exhibits a mean coefficient of friction as well as a tolerance range which was approximately 0.01 to 0.02 higher than that of RLGMO. However, in the Phase II testing the absolute value of the coefficient of friction results for both lubricants is shifted slightly higher than in the original testing, producing 90/95 confidence range up to 0.134 (K-500/K-500/Carbon Steel) for Molykote P37 on the 0.75-inch fasteners and a range up to 0.144 (K-500/Monel 400/Carbon Steel) on the larger 1.5-inch fastener. Although close examination of the large diameter fastener results (see Appendix C, Data Sets 61-65 and 156-160) indicate that the ranges for both lubricants are skewed higher due to the final torque increment which exhibits a large non-linear increase in coefficient of friction possibly due to the lower strength of the Monel 400 nut. Reanalyzing the data excluding the highest load increment reduces the maximum of the Molykote P37 range to 0.135, which is consistent with the other K-500 data. |
| <b>Type 17-4PH</b> | As mentioned above, a significant difference was observed between the lubricants when a Type 316 stainless steel washer was employed. The Molykote P37 exhibited a significant decrease in coefficient of friction from the high Cycle 1 results to Cycle 2 results for the four assemblies using the Type   |

316 washer, but no difference on the one assembly which used a carbon steel washer, since the coefficient of friction for Cycle 1 and Cycle 2 were low. Therefore, it appears that the interaction between the Type 316 nut and washer results in a significant increase in the initial coefficient of friction for the Molykote P37 while the RLGMO was better at mitigating this effect. Since austenitic stainless alloys are known to be prone to galling, the higher coefficient of friction was not surprising. These types of material combinations should be evaluated using ranges similar to that previously discussed for unplated Alloy 625.

#### **Alloy 625**

The Alloy 625 assemblies produced mixed results. The additional set of commercially procured fasteners with Alloy 625 washers (Alloy Code II) duplicates the results of the original test program producing coefficients of friction consistent with the previous range. The use of chromium plating, as expected provides a significant reduction in the coefficient of friction. However, the two 0.75-inch fasteners, IMC2 and IMC3, which are actual production hardware, result in a low coefficient of friction range comparable to any of the alloy steel assemblies. As the fastener size increases to 1.75 inches and ultimately 2.0 inches, the Molykote P37 coefficient of friction diverges from that of the RLGMO. Also, eventually in the 2.0-inch size, the Molykote P37 friction exceeds the previous range recommended for Alloy 625. A possible explanation for the lower coefficient of friction for the 0.75-inch fasteners is the use of the heavy hex nuts with the larger diameter bearing face. Examination of the 'IM' nuts and washers indicated that the actual bearing area was significantly larger with the heavy hex nuts than with the smaller commercial nuts. For the same load, this would have resulted in a lower bearing stress and lower tendency for galling. However, as the fastener size increased, even the larger nuts and bearing area did not help maintain a reasonable coefficient of friction range for the Molykote P37. As discussed in the **Surface Coating** paragraph below, the use of coating such a chromium plating may reduce the coefficient of friction on the larger fastener sizes.

#### **Titanium**

For the titanium combination tested, both Molykote P37 and RLGMO exhibited essentially identical coefficient of friction ranges. The tolerance ranges for both lubricants extend up to coefficients of 0.14. Although neither lubricant exhibits any significant difference from Cycles 1 through 3, they both exhibit increasing coefficients of friction at the higher load increments, suggesting that an additional interaction is occurring between the materials at higher loads.

#### **Size Effects**

The Molykote P37 appears to be more sensitive to size effects above 1.5 inches in diameter than RLGMO. Up to this size both lubricants exhibited a slight increase in the coefficient of friction values at approximately the same rate; however, for the 2.0-inch Alloy 625 fasteners the Molykote P37 coefficient of friction significantly exceeds that of RLGMO, resulting a Cycle 1 mean value as high as 0.176 compared to 0.117 for RLGMO. For this size fastener the required load may be resulting in a breakdown of the Molykote P37's ability to properly perform, although it is noted that an improvement was observed for Cycles 2 and 3.

#### **Run-in Cycles**

For most alloy combinations tested a significant decrease in the coefficient of friction values was observed between Cycle 1 and Cycle 2, indicating that a run-in cycle or pretorquing step is valuable in controlling the final coefficient of friction value. This difference was least noticeable for the alloy steel combinations, the chromium plated Alloy 625 assemblies and for the 0.75-inch

unplated Alloy 625 fasteners with the heavy hex nuts. The plating helps to reduce the tendency to gall for susceptible materials during the first torque cycle.

|                                      |  |
|--------------------------------------|--|
| <b>Washer Materials</b>              | The effect of washer (bearing) material was most significant when materials which are known to be prone to galling were used, such as previously discussed for the Type 17-4 PH assemblies. Higher coefficients of friction were noted for the alloy steel assemblies which used a Type 430 stainless steel lock plate. Changing washer materials in conjunction with the K-500 studs did not produce any significant differences or trends. Likewise, no significant difference was observed by changing from carbon steel washers to Alloy 625 washers for the Alloy 625 assemblies. |
| <b>Surface Coating</b>               | Surface coating provides a significant benefit in both decreasing the coefficient of friction range as well as narrowing the standard deviation of the data compared to the equivalent materials in the uncoated condition. The three types of surface treatments tested were: manganese phosphate coating and zinc plating on alloy steel, and chromium plating on Alloy 625.   |
| <b>Class of Fastener Fit</b>         | No significant difference was observed between Class 2 (Alloy Code IMC2) and Class 3 (IMC3) Alloy 625 fasteners tested, implying that the tighter thread tolerances for the Class 3 fit does not have an influence on the coefficient of friction value.   |
| <b>Manufacturing Method</b>          | No significant difference was observed between machine and rolled threads.   |
| <b>Potential Alternate Lubricant</b> | Limited testing (six different fastener assemblies) was performed with the new metallic-free lubricant, labeled as N7000. The results of the testing with N7000 are provided at the end of Appendix C. In general, this lubricant produced coefficient of friction values which exceed those of Molykote P37 by approximately 0.01 for all three torque cycles.  |

One obvious exception was the original Alloy 625 combination (Alloy Code I) in which the N7000 values were significantly less than either Molykote P37 or RLGM0. This result was so far out of line with the other data that the test laboratory was requested to repeat the test with a single spare Alloy 625 fastener assembly. This repeat test produced a result which was more expected. Although no explanation as to the source of the low values is offered, the retest values are considered more representative based on the other assemblies tested.

Based on the results of the limited screening testing, N7000 would not have been selected over Molykote P37 if it had been included in the original test matrix.

#### Use of the Coefficient of Friction Data

The tolerance ranges provided in Appendices B and C include data over a wide range of loading conditions, that is, up to 2/3 of the yield strength of the stud material. In many applications, applied loads will be significantly less than this limit. For some of the alloys tested the coefficient of friction increases with increasing load; therefore, the raw data should be consulted to get a more representative indication of coefficient of friction for the range of load in question.

Table 5 Run-in Coefficient of Friction Values

| STUD MATERIAL   | ALLOY CODE<br>(Note 1) | LUBRICANT    |           |                 |       |           |                 |
|---|------------------------|--------------|-----------|-----------------|-------|-----------|-----------------|
|   |                        | Molykote P37 |           |                 | RLGMO |           |                 |
|   |                        | Mean         | Std. Dev. | 90/95 Tolerance | Mean  | Std. Dev. | 90/95 Tolerance |
| Alloy Steel   | A                      | 0.097        | 0.007     | 0.076 - 0.118   | 0.092 | 0.003     | 0.083 - 0.101   |
|   | AM                     | 0.099        | 0.010     | 0.075 - 0.122   | 0.097 | 0.005     | 0.084 - 0.110   |
|   | P                      | 0.088        | 0.004     | 0.078 - 0.098   | 0.089 | 0.008     | 0.069 - 0.109   |
|   | AR1                    | 0.111        | 0.010     | 0.086 - 0.135   | 0.117 | 0.005     | 0.103 - 0.130   |
|   | AZ                     | 0.086        | 0.005     | 0.074 - 0.098   | 0.097 | 0.009     | 0.074 - 0.119   |
|   | AS                     | 0.095        | 0.016     | 0.053 - 0.137   | 0.091 | 0.024     | 0.027 - 0.155   |
| K-500   | M                      | 0.102        | 0.008     | 0.082 - 0.122   | 0.088 | 0.009     | 0.066 - 0.110   |
|   | MK                     | 0.125        | 0.009     | 0.101 - 0.147   | 0.105 | 0.007     | 0.087 - 0.123   |
|   | MCU                    | 0.131        | 0.014     | 0.090 - 0.171   | 0.126 | 0.009     |                 |
|   | MH                     | 0.147        | 0.006     |                 | 0.139 | 0.006     |                 |
|   | MS                     | 0.141        | 0.011     |                 | 0.124 | 0.009     |                 |
|   | MI                     | 0.141        | 0.010     |                 | 0.122 | 0.007     |                 |
|   | MA                     | 0.140        | 0.014     | 0.105 - 0.175   | 0.108 | 0.013     | 0.075 - 0.140   |
|   | MA<br>(Note 2)         | 0.135        | 0.010     | 0.110 - 0.160   | 0.103 | 0.009     | 0.079 - 0.127   |
| Alloy 625   | I                      | 0.164        | 0.021     | 0.112 - 0.216   | 0.164 | 0.025     | 0.102 - 0.226   |
|   | ICR                    | 0.105        | 0.011     | 0.079 - 0.131   | 0.104 | 0.007     | 0.088 - 0.121   |
|   | II                     | 0.149        | 0.015     | 0.113 - 0.185   | 0.160 | 0.015     | 0.122 - 0.197   |
|   | IMC2                   | 0.111        | 0.010     | 0.087 - 0.135   | 0.102 | 0.015     |                 |
|   | IMC3                   | 0.101        | 0.008     | 0.082 - 0.120   | 0.109 | 0.006     |                 |
|   | IMA                    | 0.122        | 0.020     | 0.070 - 0.174   | 0.093 | 0.016     |                 |
|   | IMB                    | 0.176        | 0.040     | 0.066 - 0.285   | 0.117 | 0.014     |                 |
| Titanium  | T                      | 0.117        | 0.009     | 0.094 - 0.139   | 0.115 | 0.010     | 0.091 - 0.139   |
| Type 17-4PH   | SS                     | 0.163        | 0.015     | 0.125 - 0.202   | 0.130 | 0.010     | 0.103 - 0.156   |
|   | SSC                    | 0.112        | 0.010     |                 | 0.115 | 0.002     |                 |
| Notes:<br>(1) See the Key to the Alloy Codes located in Table 7.<br>(2) Same as MA, excluding the highest torque increment. |                        |              |           |                 |       |           |                 |

Table 6 Design Coefficient of Friction Values

| STUD MATERIAL | ALLOY CODE<br>(Note 1) | LUBRICANT    |           |                 |       |           |                 |
|---------------|------------------------|--------------|-----------|-----------------|-------|-----------|-----------------|
|               |                        | Molykote P37 |           |                 | RLGMO |           |                 |
|               |                        | Mean         | Std. Dev. | 90/95 Tolerance | Mean  | Std. Dev. | 90/95 Tolerance |
| Alloy Steel   | A                      | 0.097        | 0.005     | 0.082 - 0.112   | 0.088 | 0.004     | 0.076 - 0.100   |
|               | AM                     | 0.103        | 0.009     | 0.081 - 0.125   | 0.090 | 0.007     | 0.072 - 0.108   |
|               | P                      | 0.090        | 0.005     | 0.078 - 0.102   | 0.083 | 0.005     | 0.071 - 0.095   |
|               | AR1                    | 0.121        | 0.011     | 0.094 - 0.149   | 0.111 | 0.005     | 0.099 - 0.123   |
|               | AZ                     | 0.081        | 0.007     | 0.063 - 0.100   | 0.082 | 0.010     | 0.058 - 0.106   |
|               | AS                     | 0.080        | 0.015     | 0.041 - 0.120   | 0.079 | 0.014     | 0.041 - 0.116   |
| K-500         | M                      | 0.094        | 0.008     | 0.074 - 0.114   | 0.075 | 0.006     | 0.060 - 0.090   |
|               | MK                     | 0.115        | 0.008     | 0.096 - 0.134   | 0.095 | 0.008     | 0.077 - 0.114   |
|               | MCU                    | 0.097        | 0.011     | 0.069 - 0.125   | 0.100 | 0.011     |                 |
|               | MH                     | 0.119        | 0.009     |                 | 0.105 | 0.010     |                 |
|               | MS                     | 0.105        | 0.014     |                 | 0.097 | 0.007     |                 |
|               | MI                     | 0.112        | 0.007     |                 | 0.112 | 0.007     |                 |
|               | MA                     | 0.120        | 0.010     | 0.095 - 0.144   | 0.106 | 0.009     | 0.085 - 0.127   |
|               | MA<br>(Note 2)         | 0.117        | 0.007     | 0.098 - 0.135   | 0.102 | 0.008     | 0.080 - 0.123   |
| Alloy 625     | I                      | 0.108        | 0.010     | 0.083 - 0.133   | 0.113 | 0.014     | 0.078 - 0.148   |
|               | ICR                    | 0.100        | 0.012     | 0.070 - 0.130   | 0.094 | 0.013     | 0.062 - 0.126   |
|               | II                     | 0.111        | 0.009     | 0.088 - 0.134   | 0.118 | 0.012     | 0.089 - 0.148   |
|               | IMC2                   | 0.089        | 0.010     | 0.065 - 0.113   | 0.101 | 0.006     |                 |
|               | IMC3                   | 0.087        | 0.008     | 0.067 - 0.106   | 0.104 | 0.006     |                 |
|               | IMA                    | 0.108        | 0.017     | 0.063 - 0.152   | 0.099 | 0.012     |                 |
|               | IMB                    | 0.129        | 0.028     | 0.051 - 0.207   | 0.106 | 0.014     |                 |
| Titanium      | T                      | 0.113        | 0.014     | 0.078 - 0.149   | 0.107 | 0.014     | 0.073 - 0.141   |
| Type 17-4PH   | SS                     | 0.121        | 0.015     | 0.082 - 0.160   | 0.098 | 0.012     | 0.066 - 0.130   |
|               | SSC                    | 0.110        | 0.006     |                 | 0.083 | 0.007     |                 |

## Notes:

- (1) See the Key to the Alloy Codes located in Table 7.
- (2) Same as MA, excluding the highest torque increment.

Table 7 Key to Tables 5 and 6

| ALLOY CODE | ALLOY COMBINATION              |                       |                            | COMMENTS  |
|------------|--------------------------------|-----------------------|----------------------------|---|
|            | Stud                           | Nut                   | Washer                     |   |
| A          | AISI 4140                      | Carbon Steel, Gr 2H   | Carbon Steel               | Rolled threads                                      |
| AM         | AISI 4140                      | Carbon Steel, Gr 2H   | Carbon Steel               | Machined threads                                    |
| P          | AISI 4140, Mn Phosphate Coated | Carbon Steel, Gr 2H   | Carbon Steel               | Rolled threads                                      |
| AR1        | AISI 4140                      | Carbon Steel, Gr 2H   | Carbon Steel               | 1.5 inches  |
| AZ         | Steel, Grade 5, Zinc plated    | Carbon Steel, Grade 5 | Carbon Steel               | Rolled threads                                      |
| AS         | AISI 4340                      | AISI 4340             | Type 430 Stainless Nutlock | Machined threads 1.0 inches                         |
| M          | K-500                          | Monel 400             | Carbon Steel               | Rolled threads                                      |
| MK         | K-500                          | K-500                 | Carbon Steel               | Rolled threads                                      |
| MCU        | K-500                          | K-500                 | 70-30 Cu-Ni                | Rolled threads                                      |
| MH         | K-500                          | K-500                 | HY 80                      | Rolled threads                                      |
| MS         | K-500                          | K-500                 | Type 430                   | Rolled threads                                      |
| MI         | K-500                          | K-500                 | Alloy 625                  | Rolled threads                                      |
| MA         | K-500                          | Monel 400             | Carbon Steel               | Rolled threads 1.5 inches                           |
| I          | Alloy 625                      | Alloy 625             | Carbon Steel               | Rolled threads                                      |
| ICR        | Alloy 625, Chromium plated     | Alloy 625             | Carbon Steel               | Rolled threads                                      |
| II         | Alloy 625                      | Alloy 625             | Alloy 625                  | Rolled threads                                      |
| IMC2       | Alloy 625                      | Alloy 625             | Alloy 625                  | Military Specification Machined threads Class 2     |
| IMC3       | Alloy 625                      | Alloy 625             | Alloy 625                  | Military Specification Machined threads Class 3     |
| IMA        | Alloy 625                      | Alloy 625             | Alloy 625                  | Military Specification Machined threads 1.75 inches |
| IMB        | Alloy 625                      | Alloy 625             | Alloy 625                  | Military Specification Machined threads 2.00 inches |
| T          | Titanium, Gr 5                 | Alloy 625             | Carbon Steel               | Rolled threads                                      |
| SS         | Type 17-4PH Stainless Steel    | Type 316 stainless    | Type 316 stainless         | Rolled threads                                      |
| SSC        | Type 17-4PH Stainless Steel    | Type 316 stainless    | Carbon Steel               | Rolled threads                                      |

### Anti-Seizing Test Results

To begin this test a coefficient of friction value of 0.10 was assumed in order to develop torque values with which to load the test assemblies. Each test assembly was given one run-in cycle to the calculated torque value, disassembled, cleaned, relubricated and retorqued prior to placing in an oven at 650°F. Based on the coefficient of friction testing results, the assumed coefficient of friction of 0.10 was within the range for all lubricants except NIKAL, Neolube No. 650 and NM-91. For NIKAL and NM-91, the coefficient of friction of 0.10 is below the determined coefficient of friction range, resulting in lower loads on these studs than the test assemblies for the other lubricants. However, both of these lubricants required high breakaway torques, indicating that their actual performance would have been even worse had higher loads (torques) been used. For Neolube No. 650 a coefficient of friction of 0.10 was actually above the determined range, indicating higher loads were applied to these assemblies than to the others.

The tabulated breakaway torque results for the anti-galling test are shown in Tables 1 through 3 in Appendix D. After one week of exposure approximately half of the 30 test assemblies still exhibited evidence of moisture after the assembly was untorqued and examined. Except for one test assembly, after three weeks of exposure, the lubricant on test assemblies had completely dried. That is, the oil constituent had oxidized, leaving only the solid anti-seizing additives. After six weeks of exposure the test assemblies had completely dried lubricant. Once dried, all of the candidate lubricants were easily removed with a nylon brush as they formed a dry powder or dust. The fasteners which had moist lubricant present could be cleaned with a cloth, but it took more time because residual lubricant smeared. Only those assemblies coated with RLGMO or MDSI required wire brushing to remove the dried baked on lubricant. Even after wire brushing, visual evidence of RLGMO was still present on the six-week assemblies.

Based on the 6- and 10-week anti-seize test results, Molykote P37 exhibited the best performance of any candidate lubricant. For both the alloy steel and K-500/Monel 400 fastener combinations, the breakaway torques for Molykote P37 were less than 40 percent higher than the installation value. For the stainless steel fasteners the breakaway torque is approximately 2.5 times the installation value. This material combination, that is, unplated stainless steel studs and nuts, is considered a worst case. For RLGMO the breakaway torques on alloy steel and K-500/Monel 400 were the same as for Molykote P37. On the unplated stainless steel fasteners, the RLGMO breakaway torques were only 60 percent higher than installation values, indicating a noticeable difference between the two lubricants. Breakaway torques for MDSI were lower than either the Molykote P37 or RLGMO, although during the untorquing audible clicking accompanied by jumping of the torque wrench follower occurred in all of the MDSI assemblies raising a question as to the precise torque values reported. Somewhat higher breakaway torque values are, therefore, expected if MDSI is replaced with Molykote P37.

### Anti-Galling Test Results

Tables 1 through 6 of Appendix E provide the raw data for the anti-galling test. For each alloy an initial test assembly was tested without lubricant and in each case galling or seizing occurred within the first four cycles, confirming that the material combinations without lubrication will gall. In general, all lubricant/material combinations, except Never Seez and MDSI, completed the first eight cycles with no signs of galling. On the K-500/Monel 400 and stainless steel assemblies, the Never Seez showed signs of galling by the second cycle via audible clicking accompanying erratic jumps on the load cell gage. The clicking and uneven loading increased in frequency on each subsequent cycle until the testing was stopped after four cycles on the K-500/Monel 400 assemblies and six and seven cycles on the two stainless steel assemblies. The MDSI lubricated K-500/Monel 400 and alloy steel assemblies showed erratic increases in the installation torque values during the first eight cycles. Galling was visually observed on the

threads during the cleaning step between Cycles 8 and 9.

In general, all lubricants required the highest torque value on Cycle 1, which then decreased to a relatively stable value through Cycle 8. For some lubricants, primarily NM-91 and N2000, a small increase in torque was seen on Cycle 5, which represented the reapplication of fresh lubricant on a cleaned, although previously used assembly. The higher values observed on Cycle 1 and occasionally at Cycle 5 represent the run-in cycle for the lubricant on a clean surface. It has been established by previous testing that during the initial loading of a new fastener a higher coefficient of friction exists compared to subsequent loading cycles for the same fastener assembly. This is seen clearly in the coefficient of friction results. As long as the torque values remained relatively constant or decreased between Cycles 2 and 8 galling was not suspected. With the exception of the small increase on Cycle 5 mentioned above, except NIKAL and MDSI, the lubricants completed eight cycles without galling.

To provide a more severe test of the lubricants ability to prevent galling, the load was increased to the stud material's yield strength during the last four cycles. As seen in the data of Appendix E, when the load was increased to the yield strength, most fasteners required a higher torque value on Cycle 9, which generally decreased during the final three cycles. Again this represents a run-in cycle for the higher loading. During Cycle 9 audible clicking and exceptionally high torques were noted for one of the two stainless steel test assemblies lubricated with each of the following lubricants: N5000, Neolube No. 650, Never Seez, Molykote P37 and MDSI. (Note: Testing of the assemblies lubricated with NIKAL had been discontinued prior to Cycle 9 due to severe galling.) On Cycle 10 the torque values for all of these assemblies decreased and remained stable through Cycle 12. These lubricants exhibited slightly more visible evidence of galling on the stainless steel assemblies than the remaining four lubricants: N1000, N2000, NM-91 and RLGMO. Since this event was only seen on the stainless steel assemblies at the load equal to the yield strength and torques for subsequent cycles returned to more expected values, these results are not considered significant because of the limited usage of austenitic stainless steel fasteners. In addition, Cycles 9 through 12 represent a severe over-test because fasteners in service are not intentionally preloaded to yield strength.

#### Detrimental Material Evaluation

Five of the eight candidates completely met the detrimental material limits, while two of the remaining three exceeded the limit for one element by less than 10 ppm. The final lubricant (NM-91) contained almost 700 ppm of sulfur.

#### Health and Environmental Evaluation

The MSDS for the eight candidate lubricants were reviewed for potential generation of hazardous wastes. The review indicated that none of the candidate lubricants contain hazardous substances per the Code of Federal Regulations, Title 40, Part 261; therefore, the use of any of these lubricants would not lead to the generation of a hazardous wastes based on their composition or physical/chemical characteristics and all are equally acceptable from a disposal standpoint.

Off-gas testing of each candidate lubricant was performed to determine the composition of volatile products produced during a 48 hour exposure at 650°F. Molykote P37, Neolube No. 650 and NM-91 off gassed formaldehyde, which is a suspected human carcinogen as classified by ACGIH. The sources of formaldehyde in Molykote P37 are mineral oil and polyisobutylene, which are essential ingredients in the formulation. It would not be feasible to eliminate the sources of formaldehyde. However, formaldehyde would not be released at temperatures below about 600°F. For all candidate lubricants, the organic constituents off-gas during the first 24 hours of

heating indicating that the first 24 hours is the period of greatest concern. The recommended safety practices to be followed when using Molykote P37 are as follows:

- ▶ use chemical worker goggles
- ▶ use neoprene or equivalent gloves
- ▶ avoid of extreme heat, such as during welding, and motorized methods to remove the residual lubricant, such as wire brushing
- ▶ use adequate ventilation during the first 24 hours of high temperature operations
- ▶ wipe off excess lubricant before hot operations

Independently, a certified industrial hygienist reviewed the MSDS for the candidate lubricants for human toxicological concerns. The results are summarized as follows:

- ▶ nickel and nickel compounds are known human carcinogens (Group 1 Carcinogens by the IARC)
- ▶ copper and nickel produce chronic toxic metal effects in humans, although copper is less of a human toxicological problem than nickel

Molykote P37 does not contain nickel or copper, and thus is not a human toxicological concern.

### **Corrosion Testing Results**

No corrosion effects were observed in any fastener specimen lubricated with Molykote P37. Corrosion effects were observed with several of the other candidate replacement lubricants. The following summarizes the results of the corrosion testing:

- ▶ None of the eight candidate replacement lubricants, including Molykote P37, caused any corrosion effects in air which are different from or more apparent than that caused by RLGMO, MDSI or from corrosion effects under similar conditions of exposure to unlubricated fasteners in any of the tested materials.
- ▶ N1000, Never Seez and NM-91 caused localized corrosion, that is, pitting and crevice corrosion, of K-500 fasteners which was more apparent than that occurring in unlubricated K-500 fasteners under similar conditions of salt water exposure.
- ▶ N1000 intergranularly attacked Type 304 stainless steel fasteners in salt water exposure.
- ▶ None of the eight candidate replacement lubricants for RLGMO caused any galvanically assisted localized corrosion effects in air or distilled water. These corrosion effects which are different from or more apparent than that caused by RLGMO, MDSI or from corrosion effects under similar conditions of exposure to unlubricated fasteners in any of the tested materials.

## V. Conclusions

Based on the results of the initial testing, Westinghouse concluded that Dow Corning Molykote P37 is the best replacement for RLGMO in that it best simulates the coefficient of friction range, the anti-galling and anti-seizing properties of the RLGMO, is non-hazardous, poses minimal health risks and is non-corrosive to the fastener alloys evaluated. Initial testing also indicated that Molykote P37 could be used as a replacement for MDSI based on the improved coefficient of friction range. However, because MDSI is not hazardous and does possess the best anti-seizing resistance of any lubricant tested, an across the board replacement was not undertaken.

Additional testing performed in a Phase II program confirmed the choice of Molykote P37 and greatly expanded the coefficient of friction database to additional fastener alloy combinations. Dow Corning Molykote P37 Paste meets the requirements of Commercial Item Description, A-A-59004, "Anti-Galling Compound, Thread Lubricating, Seizing Resistant, and Calcium Hydroxide Containing".

The selection of Molykote P37 by Westinghouse does not reflect functional deficiencies with the other candidate lubricants in this evaluation but rather that Molykote P37 was the best match for RLGMO based on the Westinghouse criteria. Readers should compare the results discussed herein against the specific application requirements prior to selection of a lubricant.

## VI. Acknowledgments

The authors wish to acknowledge N.P. Grado for designing and coordinating the corrosion testing, L.N. Eaton for assisting in the evaluation of the coefficients of friction, K.M. Goellner and R.D. Hays of the Westinghouse Bettis Laboratory for performing the toxicological evaluations, R. Hagar of the Naval Sea Systems Command for coordinating the environmental off gas testing and E.E. Toomey for assistance in procuring the test material and expediting the placement of the testing contracts. The authors also acknowledge the contributions of S.W. Bodner of the Naval Sea Systems Command for his sponsorship and continued interest in this work.

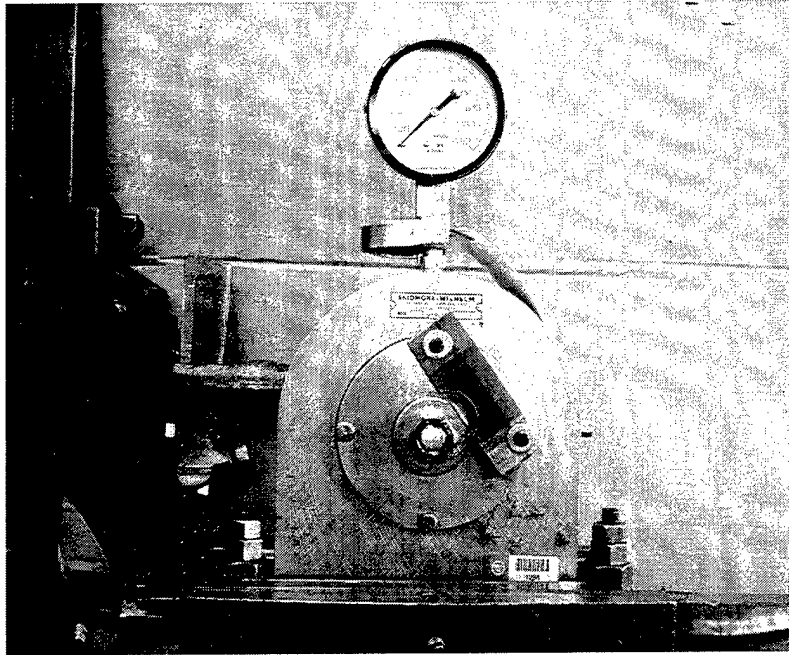


Figure 1. Skidmore-Wilhelm Torque Tension Unit, Model RL

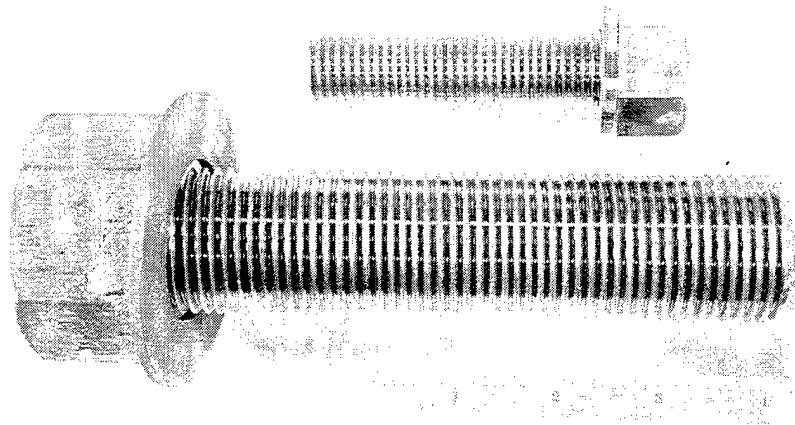


Figure 2. Typical Fastener Assemblies: 1.5-8UNC-2A Monel K-500 (Alloy Code MA) and 0.75-10UNC-3A Alloy 625 (Alloy Code IMC3)

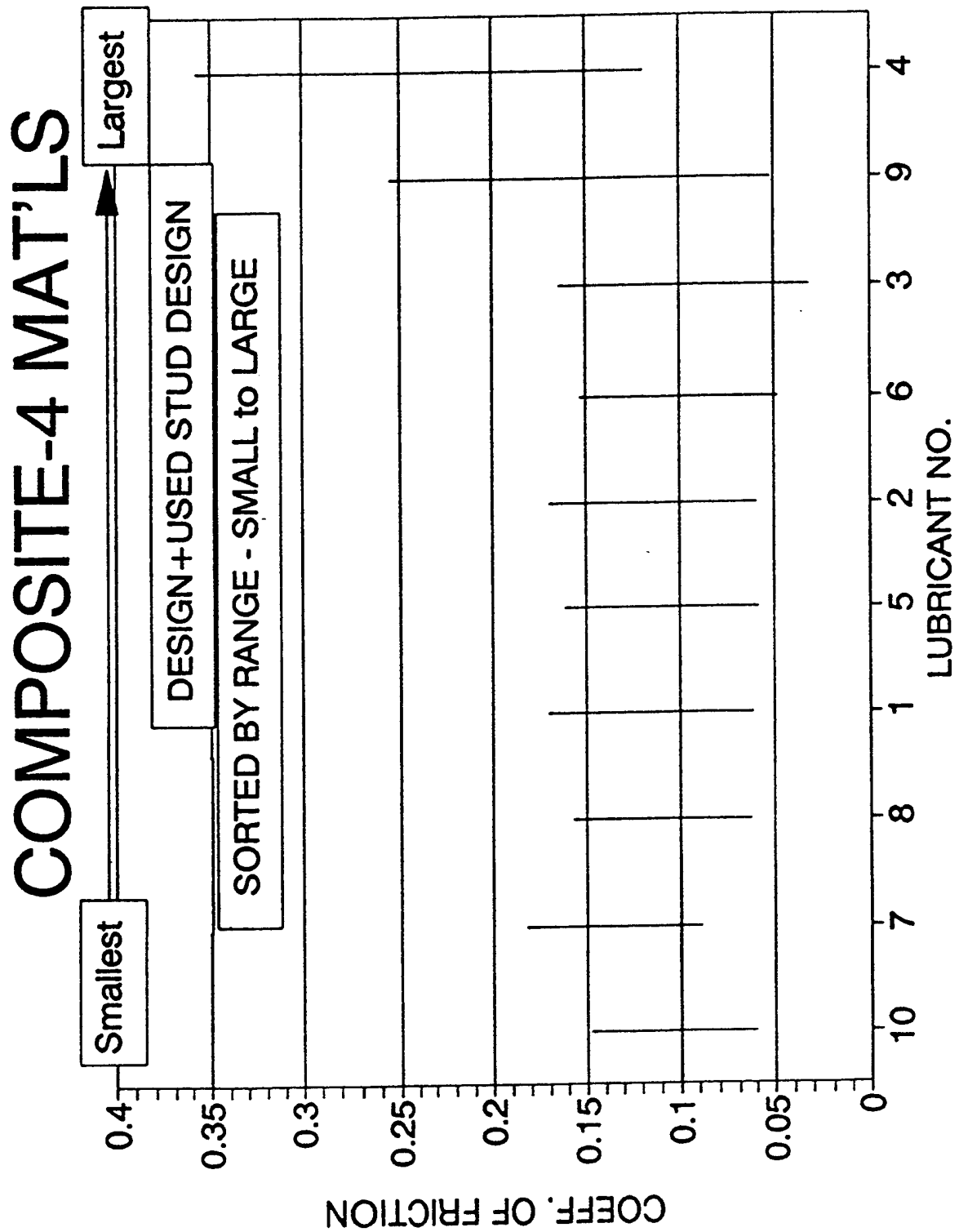


Figure 3. Coefficient of Friction Ranges of the Phase I Lubricants

## Appendix A

### EQUATION FOR CALCULATING THE COEFFICIENT OF FRICTION ( $\mu$ )

$$\mu = - \left[ \frac{C + \sqrt{C^2 - 4D_b A \sin \lambda}}{2 D_b \sin \lambda} \right]$$

where:

$$C = - \left[ D_b \cos \alpha_n \cos \lambda + \frac{24T}{P} \sin \lambda + E \cos \lambda \right]$$

$$A = \left[ \frac{24T}{P} \cos \alpha_n \cos \lambda - E \cos \alpha_n \sin \lambda \right]$$

T = Torque, ft-lb.

P = Axial load, lb.

E = Minimum pitch diameter, in.

$D_h$  = Flats diameter of nuts, in.

B = Diameter of hole in washer, in.

$$D_b = \frac{2}{3} \frac{D_h^3 - B^3}{D_h^2 - B^2}$$

N = Number of threads per inch

$\alpha$  = One-half the thread profile angle

$\lambda$  = Helix angle =  $\arctan \frac{1}{N E \pi}$

$\alpha_n$  =  $\arctan (\tan \alpha \cos \lambda)$

## **Appendix B**

### **SUMMARY STATISTICS OF COEFFICIENT OF FRICTION DATABASE OF REPLACEMENT CANDIDATES FOR RED LEAD AND GRAPHITE IN MINERAL OIL (RLGMO)**

This appendix includes the calculated coefficient of friction data, based on the equation of Appendix A. The actual test information, i.e, the individual loads and corresponding torque values, and the detailed statistical analysis can be obtained by requesting from the authors at:

Westinghouse Electric Company  
Plant Apparatus Division  
500 Penn Center Boulevard  
Pittsburgh, PA 15235-5713

## **SUMMARY STATISTICS OF COEFFICIENT OF FRICTION DATABASE OF REPLACEMENT CANDIDATES FOR RED LEAD AND GRAPHITE IN MINERAL OIL (RLGMO)**

### **I. PURPOSE**

The purpose of this enclosure is to provide the analysis (summary statistics) of the torque-tension test results of coefficient of friction data of lubricant replacement candidates for red lead and graphite in mineral oil (RLGMO).

### **II. BACKGROUND**

The final approved coefficient of friction testing matrix for RLGMO replacement lubricant candidates includes ten lubricants and four (4) material combinations. This is an incomplete blocked experiment with only minor perturbations\* from a complete blocked experiment. Forty sets of torque-tension tests were performed. The data from these tests are used to establish the coefficient of friction for each lubricant/material combination. There are five (5) studs per combination and four loading sequences. Each loading sequence contains six (6) values of coefficient of friction; five (5) on the loading portion with the highest load equal to 2/3 yield strength and one (1) break-away value.

\* For the Alloy Steel (B7) Stud/Nut fasteners, only two (2) studs were tested.

\*\* Breakaway coefficient of friction not provided in this enclosure.

### **III. DESCRIPTION OF SUMMARY ANALYSIS**

#### **A. Summary Statistics**

The analysis of the torque-tension coefficient of friction testing focused on summary statistics for each of the 40 dataset combinations. Main features include an overall assessment of the variation of the coefficient of friction, mean values, standard deviations and the range of the data.

Most of the coefficient of friction distributions can be characterized by a normal distribution with a smaller standard deviation for the lower half than the upper half of the distribution.

#### **B. Stud and Load Sequence Subgrouping**

The data are grouped by material and provided in tables of the attachments (one material combination in each attachment) to this enclosure. A mean value and standard deviation were calculated for each stud loading portion of the test. In addition, mean values and standard deviations were calculated for each of the four (4) loading sequences which include all five (5) studs.

The categories of the 4-step loading sequences are defined as:

1. run-in,
2. design,
3. used stud run-in, and
4. used stud design.

The initial run-in represents a new stud cleaned and lubricated, and then torqued. The stud is unloaded, lubricated and loaded again as in the field application. This represents the design values of coefficient of friction. The stud is unloaded, cleaned and lubricated and loaded again. This represents a used stud run-in. The stud is unloaded, lubricated, and loaded again, representing the design case for a used stud. A test of significant differences of the mean values and variances for the each material/lubricant combination are calculated and provided for the coefficient of friction data for (a) the design vs the run-in and (b) the used stud design vs the design categories. Significant difference here is calculated at the 95 percent confidence level.

**C. Analysis of Variance (ANOVA) to Measure Stud-to-Stud Variations**

An ANOVA is carried out for every lubricant/material combination to measure the significance of the stud-to-stud variation compared to the within stud variation of coefficient of friction. The application here is to establish whether the variations of the mean values for each stud are significantly different from the overall mean value. The inference here is, if there is no significant difference of mean values, the testing of five (5) can represent the coefficient of friction for all studs. A significant variation from stud-to-stud suggests that a tolerance interval, based on degrees of freedom of the testing, should be factored into the application of coefficient of friction values for all studs.

**D. Ranking Criteria for All Stud/Lubricant Combinations.**

The results of the lubricant coefficient of friction analyses described above were used to establish a relative ranking of lubricant candidates for each of the material combinations. See, for example, Tables I - VIII which list the summary statistics for each lubricant/material combination. A sort (ranking of lubricants) by features (e.g., range of coefficient of friction) was provided for consideration to choose potential lubricants for final recommendation of replacement for RLGMO. A small range is desirable since this would allow better predictable values of loading stresses for design calculations. A stud-to-stud variation would not be a desirable characteristic, since some adjustment must be made for use in design values provided.

**IV. RESULTS**

As one criteria for ranking the lubricant coefficient of friction values, a tolerance interval (90 percent/95 percent from reference (a)) was calculated for each range of the design values of coefficient of friction for each lubricant/material combination and an overall composite ranking. This analysis was extended to used-stud design tolerance ranges and to the initial run-in tolerance ranges. The maximum and minimum values of the tolerance range were then obtained for each lubricant for all material combinations used. These values are listed in Tables IX through XIV. A composite plot of these ranges of coefficient of friction were developed for each of the three categories; run-in (Figure 1), design (Figure 2), and used-stud design (Figure 3). In addition, an individual plot of the relative ranking of the design coefficient of friction tolerance ranges for each material combination are provided in Figures 4 through 7. The data used for Tables I through XIV and Figures 1 through 7 are from the detailed datasets of coefficient of friction values in Attachments I through IV.

**V. REFERENCES**

(a) Experimental Statistics, National Bureau of Standards Handbook 91, August 1, 1963

Attachments: I - Phase I - Coefficient of Friction Dataset: Alloy 625  
II - Phase I - Coefficient of Friction Dataset: Monel K-500 (K-Monel)/Monel 400  
III - Phase I - Coefficient of Friction Dataset: AISI 4140 Phosphate Coated  
IV - Phase I - Coefficient of Friction Dataset: AISI 4140 Alloy Steel (B7)

**TABLE I**  
**SUMMARY STATISTICS FOR LUBRICANT CANDIDATES**

**Material Combination: Inconel 625 Stud/Nut**

| LUBRICANT<br>NUMBER | COEFFICIENT OF FRICTION<br>OVERALL 5 STUDS, 4 LOADING<br>LOADING VALUES UP TO 2/3 Yield |         |       |                         | Stud-to<br>Stud<br>Change<br><br>Mean | Run-in<br>vs<br>Design<br><br>Mean | Design<br>vs Used<br>Stud<br>Design<br>Mean |
|---------------------|---|---------|-------|-------------------------|---------------------------------------|------------------------------------|---|
|                     | Mean  | Std Dev | Range | Normal<br>Distr.<br>Y/N | Signif<br>Diff.<br>Y/N*               | Signif<br>Diff.<br>Y/N*            | Signif<br>Diff.<br>Y/N*                     |
| 1                   | 0.152   | 0.037   | 0.180 | Yes                     | Yes                                   | Yes                                | No  |
| 2                   | 0.137   | 0.038   | 0.231 | Yes                     | Yes                                   | Yes                                | Yes   |
| 3                   | 0.126   | 0.042   | 0.173 | Yes                     | Yes                                   | Yes                                | Yes   |
| 4                   | 0.263   | 0.050   | 0.260 | Yes                     | Yes                                   | Yes                                | N/A **                                      |
| 5                   | 0.139   | 0.043   | 0.195 | Yes                     | Yes                                   | Yes                                | Yes   |
| 6                   | 0.143   | 0.032   | 0.122 | No                      | No                                    | Yes                                | No  |
| 7                   | 0.174   | 0.037   | 0.164 | Yes                     | No                                    | Yes                                | No  |
| 8                   | 0.127   | 0.029   | 0.125 | Yes                     | Yes                                   | Yes                                | No  |
| 9                   | 0.179   | 0.048   | 0.234 | Yes                     | Yes                                   | Yes                                | Yes   |
| 10                  | 0.127   | 0.028   | 0.129 | Yes                     | No                                    | Yes                                | Yes   |

\* Significance is at the 95% confidence level; i.e., a significant difference for the stud mean value outside of the 95% confidence interval of the overall mean value, or there is a significant difference between the design and run-in mean values at the 95% confidence level.

\*\* For Lubricant 4 only 50 values are provided. Testing was difficult and completion of the used stud testing is pending.

**TABLE II**  
**COEFFICIENT OF FRICTION RUN-IN AND DESIGN VALUES**

**Material Combination: Inconel 625 Stud/Nut**

| LUBRICANT<br>NUMBER | COEFFICIENT OF FRICTION |         |       |                |         |       |
|---------------------|-------------------------|---------|-------|----------------|---------|-------|
|                     | RUN - IN LOADING        |         |       | DESIGN LOADING |         |       |
|                     | MEAN                    | STD DEV | RANGE | MEAN           | STD DEV | RANGE |
| 1                   | 0.200                   | 0.030   | 0.068 | 0.126          | 0.018   | 0.047 |
| 2                   | 0.189                   | 0.035   | 0.168 | 0.120          | 0.020   | 0.105 |
| 3                   | 0.185                   | 0.025   | 0.086 | 0.108          | 0.023   | 0.058 |
| 4                   | 0.287                   | 0.040   | 0.200 | 0.239          | 0.048   | 0.183 |
| 5                   | 0.197                   | 0.032   | 0.113 | 0.117          | 0.018   | 0.074 |
| 6                   | 0.185                   | 0.018   | 0.067 | 0.118          | 0.014   | 0.042 |
| 7                   | 0.231                   | 0.025   | 0.098 | 0.150          | 0.013   | 0.038 |
| 8                   | 0.164                   | 0.021   | 0.066 | 0.108          | 0.010   | 0.046 |
| 9                   | 0.222                   | 0.053   | 0.171 | 0.166          | 0.036   | 0.131 |
| 10                  | 0.164                   | 0.025   | 0.086 | 0.113          | 0.014   | 0.046 |

**TABLE III**  
**SUMMARY STATISTICS FOR LUBRICANT CANDIDATES**

Material Combination: Monel K500/Monel 400 Stud/Nut

| LUBRICANT<br>NUMBER | COEFFICIENT OF FRICTION<br>OVERALL 5 STUDS, 4 LOADING<br>LOADING VALUES UP TO 2/3 Yield |            |       |                         | Stud-to<br>Stud<br>Change<br><br>Mean | Run-in<br>vs<br>Design<br><br>Mean | Design<br>vs Used<br>Stud<br>Design<br>Mean |
|---------------------|---|------------|-------|-------------------------|---------------------------------------|------------------------------------|---|
|                     | Mean  | Std<br>Dev | Range | Normal<br>Distr.<br>Y/N | Signif<br>Diff.<br>Y/N*               | Signif<br>Diff.<br>Y/N*            | Signif<br>Diff.<br>Y/N*                     |
| 1                   | 0.102   | 0.013      | 0.067 | Yes                     | Yes                                   | Yes                                | No  |
| 2                   | 0.102   | 0.011      | 0.051 | Yes                     | Yes                                   | Yes                                | No  |
| 3                   | 0.065   | 0.010      | 0.053 | Yes                     | No                                    | Yes                                | Yes   |
| 4                   | 0.161   | 0.016      | 0.077 | Yes                     | Yes                                   | No                                 | Yes   |
| 5                   | 0.090   | 0.013      | 0.059 | Yes                     | Yes                                   | Yes                                | Yes   |
| 6                   | 0.086   | 0.015      | 0.074 | Yes                     | Yes                                   | Yes                                | Yes   |
| 7                   | 0.156   | 0.009      | 0.048 | No                      | Yes                                   | Yes                                | Yes   |
| 8                   | 0.097   | 0.009      | 0.042 | Yes                     | Yes                                   | Yes                                | No  |
| 9                   | 0.087   | 0.013      | 0.065 | Yes                     | Yes                                   | No                                 | No  |
| 10                  | 0.077   | 0.010      | 0.054 | Yes                     | Yes                                   | Yes                                | Yes   |

\* Significance is at the 95% confidence level; i.e., a significant difference for the stud mean value outside of the 95% confidence interval of the overall mean value, or there is a significant difference between the design and run-in mean values at the 95% confidence level.

TABLE IV

COEFFICIENT OF FRICTION RUN-IN AND DESIGN VALUES

Material Combination: K-Monel/Monel Stud/Nut

| LUBRICANT<br>NUMBER | COEFFICIENT OF FRICTION |         |       |                |         |       |
|---------------------|-------------------------|---------|-------|----------------|---------|-------|
|                     | RUN - IN LOADING        |         |       | DESIGN LOADING |         |       |
|                     | MEAN                    | STD DEV | RANGE | MEAN           | STD DEV | RANGE |
| 1                   | 0.114                   | 0.013   | 0.041 | 0.099          | 0.010   | 0.035 |
| 2                   | 0.108                   | 0.009   | 0.031 | 0.101          | 0.009   | 0.031 |
| 3                   | 0.074                   | 0.012   | 0.042 | 0.065          | 0.008   | 0.032 |
| 4                   | 0.150                   | 0.010   | 0.034 | 0.153          | 0.014   | 0.053 |
| 5                   | 0.103                   | 0.010   | 0.040 | 0.088          | 0.010   | 0.036 |
| 6                   | 0.097                   | 0.015   | 0.056 | 0.085          | 0.015   | 0.058 |
| 7                   | 0.154                   | 0.011   | 0.048 | 0.160          | 0.009   | 0.030 |
| 8                   | 0.102                   | 0.008   | 0.026 | 0.094          | 0.008   | 0.026 |
| 9                   | 0.087                   | 0.009   | 0.030 | 0.087          | 0.014   | 0.037 |
| 10                  | 0.088                   | 0.009   | 0.027 | 0.075          | 0.006   | 0.020 |

TABLE V

SUMMARY STATISTICS FOR LUBRICANT CANDIDATES

Material Combination: AISI 4140 Phosphate Coat/AISI 4140 Stud/Nut

| LUBRICANT<br>NUMBER | COEFFICIENT OF FRICTION<br>OVERALL<br>5 STUDS, 4 LOADING |            |       |                         | Stud-to<br>Stud<br>Change | Run-in<br>vs<br>Design  | Design<br>vs Used<br>Stud<br>Design<br>Mean |
|---------------------|--|------------|-------|-------------------------|---------------------------|-------------------------|---|
|                     | LOADING VALUES UP TO 2/3 Yield                           |            |       |                         | Mean                      | Mean                    |   |
|                     | Mean   | Std<br>Dev | Range | Normal<br>Distr.<br>Y/N | Signif<br>Diff.<br>Y/N*   | Signif<br>Diff.<br>Y/N* | Signif<br>Diff.<br>Y/N*                     |
| 1                   | 0.091  | 0.009      | 0.042 | Yes                     | Yes                       | Yes                     | Yes   |
| 2                   | 0.088  | 0.008      | 0.044 | No                      | Yes                       | Yes                     | No  |
| 3                   | 0.052  | 0.008      | 0.048 | Yes                     | Yes                       | Yes                     | No  |
| 4                   | 0.143  | 0.009      | 0.045 | Yes                     | Yes                       | Yes                     | Yes   |
| 5                   | 0.079  | 0.008      | 0.036 | Yes                     | Yes                       | Yes                     | No  |
| 6                   | 0.083  | 0.006      | 0.034 | Yes                     | Yes                       | Yes                     | No  |
| 7                   | 0.110  | 0.006      | 0.034 | Yes                     | Yes                       | No                      | Yes   |
| 8                   | 0.090  | 0.005      | 0.028 | Yes                     | Yes                       | No                      | No  |
| 9                   | 0.098  | 0.018      | 0.072 | Yes                     | Yes                       | No                      | No  |
| 10                  | 0.082  | 0.007      | 0.050 | Yes                     | Yes                       | Yes                     | Yes   |

\* Significance is at the 95% confidence level; i.e., a significant difference for the stud mean value outside of the 95% confidence interval of the overall mean value, or there is a significant difference between the design and run-in mean values at the 95% confidence level.

TABLE VI

## COEFFICIENT OF FRICTION RUN-IN AND DESIGN VALUES

Material Combination: AISI 4140 Phosphate Coat/AISI 4140 Stud/Nut

| LUBRICANT<br>NUMBER | COEFFICIENT OF FRICTION |         |       |                |         |       |
|---------------------|-------------------------|---------|-------|----------------|---------|-------|
|                     | RUN - IN LOADING        |         |       | DESIGN LOADING |         |       |
|                     | MEAN                    | STD DEV | RANGE | MEAN           | STD DEV | RANGE |
| 1                   | 0.099                   | 0.004   | 0.016 | 0.092          | 0.008   | 0.026 |
| 2                   | 0.095                   | 0.005   | 0.016 | 0.085          | 0.007   | 0.024 |
| 3                   | 0.061                   | 0.007   | 0.023 | 0.048          | 0.005   | 0.024 |
| 4                   | 0.148                   | 0.008   | 0.034 | 0.136          | 0.006   | 0.023 |
| 5                   | 0.087                   | 0.005   | 0.016 | 0.0757         | 0.006   | 0.023 |
| 6                   | 0.089                   | 0.005   | 0.019 | 0.080          | 0.005   | 0.016 |
| 7                   | 0.109                   | 0.007   | 0.034 | 0.107          | 0.005   | 0.014 |
| 8                   | 0.088                   | 0.004   | 0.013 | 0.090          | 0.005   | 0.015 |
| 9                   | 0.106                   | 0.018   | 0.051 | 0.102          | 0.020   | 0.061 |
| 10                  | 0.089                   | 0.008   | 0.040 | 0.083          | 0.005   | 0.022 |

**TABLE VII**  
**SUMMARY STATISTICS FOR LUBRICANT CANDIDATES**

**Material Combination: Alloy Steel (B7) Stud/Nut**

| LUBRICANT<br>NUMBER | COEFFICIENT OF FRICTION<br>OVERALL 5 STUDS, 4 LOADING<br>LOADING VALUES UP TO 2/3 Yield |            |       |                         | Stud-to<br>Stud<br>Change<br>Mean | Run-in<br>vs<br>Design<br>Mean | Design<br>vs Used<br>Stud<br>Design<br>Mean |
|---------------------|---|------------|-------|-------------------------|-----------------------------------|--------------------------------|---|
|                     | Mean  | Std<br>Dev | Range | Normal<br>Distr.<br>Y/N | Signif<br>Diff.<br>Y/N            | Signif<br>Diff.<br>Y/N*        | Signif<br>Diff.<br>Y/N*                     |
| 1                   | 0.105   | 0.009      | 0.032 | Yes                     | N/A**                             | Yes                            | No  |
| 2                   | 0.095   | 0.009      | 0.036 | Yes                     | N/A                               | No                             | Yes   |
| 3                   | 0.059   | 0.010      | 0.039 | Yes                     | N/A                               | Yes                            | Yes   |
| 4                   | 0.148   | 0.007      | 0.029 | Yes                     | N/A                               | Yes                            | Yes   |
| 5                   | 0.095   | 0.009      | 0.030 | Yes                     | N/A                               | Yes                            | Yes   |
| 6                   | 0.105   | 0.008      | 0.036 | Yes                     | N/A                               | Yes                            | No  |
| 7                   | 0.123   | 0.007      | 0.030 | Yes                     | N/A                               | Yes                            | No  |
| 8                   | 0.099   | 0.005      | 0.025 | Yes                     | N/A                               | No                             | No  |
| 9                   | 0.102   | 0.017      | 0.062 | Yes                     | N/A                               | Yes                            | Yes   |
| 10                  | 0.088   | 0.004      | 0.018 | Yes                     | N/A                               | Yes                            | Yes   |

\* Significance is at the 95% confidence level; i.e., a significant difference for the stud mean value outside of the 95% confidence interval of the overall mean value, or there is a significant difference between the design and run-in mean values at the 95% confidence level.

\*\* This material had only 2 studs tested, not 5 as with the other material combinations.

**TABLE VIII**  
**COEFFICIENT OF FRICTION RUN-IN AND DESIGN VALUES**

**Material Combination: Alloy Steel (B7) Stud/Nut**

| LUBRICANT<br>NUMBER | COEFFICIENT OF FRICTION |         |       |                |         |       |
|---------------------|-------------------------|---------|-------|----------------|---------|-------|
|                     | RUN - IN LOADING        |         |       | DESIGN LOADING |         |       |
|                     | MEAN                    | STD DEV | RANGE | MEAN           | STD DEV | RANGE |
| 1                   | 0.117                   | 0.004   | 0.012 | 0.100          | 0.007   | 0.022 |
| 2                   | 0.101                   | 0.005   | 0.015 | 0.096          | 0.010   | 0.033 |
| 3                   | 0.071                   | 0.008   | 0.025 | 0.057          | 0.006   | 0.013 |
| 4                   | 0.152                   | 0.006   | 0.020 | 0.141          | 0.006   | 0.020 |
| 5                   | 0.101                   | 0.003   | 0.009 | 0.095          | 0.006   | 0.015 |
| 6                   | 0.111                   | 0.004   | 0.016 | 0.104          | 0.008   | 0.026 |
| 7                   | 0.125                   | 0.009   | 0.027 | 0.119          | 0.004   | 0.013 |
| 8                   | 0.097                   | 0.007   | 0.026 | 0.097          | 0.005   | 0.016 |
| 9                   | 0.123                   | 0.009   | 0.026 | 0.107          | 0.006   | 0.017 |
| 10                  | 0.092                   | 0.003   | 0.012 | 0.088          | 0.004   | 0.010 |

Table IX. Initial Run-in Values; Tolerance Ranges

| 90%/95% TOLERANCE BANDS FOR COEFFICIENT OF FRICTION SORT ON RANGE |       |         |           |          |              |          |          |       |            |
|---|-------|---------|-----------|----------|--------------|----------|----------|-------|------------|
| INITIAL RUN-IN VALUES   |       |         |           |          |              |          |          |       |            |
| LUBR.   | MEAN  | STD DEV | 90/95 TOL |          | RANKED RANGE |          | 4140 PHO |       | RANGE/MEAN |
|   |       |         | LOW       | HIGH     | LOW          | HIGH     | LOW      | HIGH  |            |
| 6   | 0.185 | 0.018   | 0.140468  | 0.229532 | 0.089064     | 0.481427 | 0.088    | 0.004 | 0.078104   |
| 8   | 0.164 | 0.021   | 0.112046  | 0.215954 | 0.103908     | 0.833585 | 0.099    | 0.004 | 0.089104   |
| 7   | 0.231 | 0.025   | 0.16915   | 0.29285  | 0.1237       | 0.535498 | 0.095    | 0.005 | 0.08263    |
| 10  | 0.164 | 0.025   | 0.10215   | 0.22585  | 0.1237       | 0.754268 | 0.089    | 0.005 | 0.07663    |
| 3   | 0.185 | 0.025   | 0.12315   | 0.24685  | 0.1237       | 0.868649 | 0.087    | 0.005 | 0.07463    |
| 1   | 0.2   | 0.03    | 0.12578   | 0.27422  | 0.14844      | 0.7422   | 0.061    | 0.007 | 0.043692   |
| 5   | 0.197 | 0.032   | 0.117832  | 0.276168 | 0.158336     | 0.803736 | 0.109    | 0.007 | 0.091682   |
| 2   | 0.189 | 0.035   | 0.10241   | 0.27559  | 0.17318      | 0.916296 | 0.089    | 0.008 | 0.069208   |
| 4   | 0.287 | 0.04    | 0.18804   | 0.38596  | 0.19792      | 0.699617 | 0.148    | 0.008 | 0.128208   |
| 9   | 0.222 | 0.053   | 0.090878  | 0.353122 | 0.262244     | 1.181279 | 0.106    | 0.018 | 0.061468   |

| 90/95 TOL  |          |   |          |    |          |   |          |   |          |
|------------|----------|---|----------|----|----------|---|----------|---|----------|
| RANGE/MEAN |          |   |          |    |          |   |          |   |          |
| LUBRICANT  |          |   |          |    |          |   |          |   |          |
| 8          | 0.224909 | 1 | 0.198919 | 2  | 0.260421 | 6 | 0.277978 | 5 | 0.284368 |
| 3          | 0.567803 | 3 | 0.317761 | 10 | 0.444764 | 4 | 0.267459 | 9 | 0.840226 |

| 90/95 TOL  |          |   |          |   |          |   |          |   |          |
|------------|----------|---|----------|---|----------|---|----------|---|----------|
| RANGE/MEAN |          |   |          |   |          |   |          |   |          |
| LUBRICANT  |          |   |          |   |          |   |          |   |          |
| 10         | 0.196826 | 5 | 0.179287 | 6 | 0.217514 | 1 | 0.206359 | 2 | 0.298812 |
| 4          | 0.238263 | 8 | 0.435588 | 3 | 0.680113 | 7 | 0.434592 | 9 | 0.441659 |

Table X. Initial Run-in Values; Tolerance Ranges

COMPOSITE MATERIALS - MIN/MAX 90/95 TOLERANCE - ALL FOUR MATERIALS

| LUBRICANT | SORT ON RANGE |          |          |
|-----------|---------------|----------|----------|
|           | MIN           | MAX      | RANGE    |
| 8         | 0.075874      | 0.215954 | 0.14008  |
| 10        | 0.065734      | 0.22585  | 0.160116 |
| 6         | 0.05989       | 0.229532 | 0.169642 |
| 1         | 0.089104      | 0.27422  | 0.185116 |
| 2         | 0.08263       | 0.27559  | 0.19296  |
| 7         | 0.091682      | 0.29285  | 0.201168 |
| 5         | 0.07463       | 0.276168 | 0.201538 |
| 3         | 0.043682      | 0.24685  | 0.203168 |
| 4         | 0.12526       | 0.38596  | 0.2607   |
| 9         | 0.061468      | 0.353122 | 0.291654 |

Table XI. Initial Design Values; Tolerance Ranges

| 90%/95% TOLERANCE BANDS FOR COEFFICIENT OF FRICTION SORT ON RANGE |               |         |          |           |          |          |               |       |       |          |          |          |
|---|---------------|---------|----------|-----------|----------|----------|---------------|-------|-------|----------|----------|----------|
| LUBR.   | DESIGN VALUES |         |          |           |          |          |               |       |       |          |          |          |
|   | MEAN          | STD DEV | INCONEL  | 90/95 TOL |          |          | RANKED RANGE/ |       |       | 4140 PHO |          |          |
|   |               |         |          | LOW       | HIGH     |          | RANGE         | MEAN  |       | MEAN     | STD DEV  |          |
| 8   | 0.108         | 0.01    | 0.08326  | 0.13274   | 0.04948  | 0.458148 |               | 0.107 | 0.005 | 0.09483  | 0.11937  | 0.02474  |
| 7   | 0.15          | 0.013   | 0.117838 | 0.182162  | 0.064324 | 0.428827 |               | 0.083 | 0.005 | 0.07063  | 0.09537  | 0.02474  |
| 6   | 0.118         | 0.014   | 0.083364 | 0.152636  | 0.069272 | 0.587051 |               | 0.08  | 0.005 | 0.06763  | 0.09237  | 0.02474  |
| 10  | 0.113         | 0.014   | 0.078364 | 0.147636  | 0.069272 | 0.613027 |               | 0.048 | 0.005 | 0.03563  | 0.06037  | 0.02474  |
| 1   | 0.128         | 0.018   | 0.081468 | 0.170532  | 0.089064 | 0.708857 |               | 0.09  | 0.005 | 0.07763  | 0.10237  | 0.02474  |
| 5   | 0.117         | 0.018   | 0.072468 | 0.161532  | 0.089064 | 0.761231 |               | 0.136 | 0.006 | 0.121156 | 0.150844 | 0.029688 |
| 2   | 0.12          | 0.02    | 0.07052  | 0.16948   | 0.08986  | 0.824667 |               | 0.076 | 0.006 | 0.081156 | 0.090844 | 0.029688 |
| 3   | 0.108         | 0.023   | 0.051098 | 0.164902  | 0.113804 | 1.053741 |               | 0.085 | 0.007 | 0.067882 | 0.102318 | 0.034636 |
| 9   | 0.166         | 0.036   | 0.076936 | 0.255064  | 0.178128 | 1.07308  |               | 0.092 | 0.008 | 0.072208 | 0.111792 | 0.039584 |
| 4   | 0.239         | 0.048   | 0.120248 | 0.357752  | 0.237504 | 0.983741 |               | 0.102 | 0.02  | 0.05252  | 0.15148  | 0.09896  |

| 90/95 TOL |               |         |          |          |          |          |               |          |       |          |          |          |
|-----------|---------------|---------|----------|----------|----------|----------|---------------|----------|-------|----------|----------|----------|
| LUBR.     | K MONEL/MONEL |         |          |          |          |          |               |          |       |          |          |          |
|           | MEAN          | STD DEV |          | LOW      | HIGH     |          | RANKED RANGE/ | B7 ALLOY |       |          | RANGE/   |          |
|           |               |         |          |          |          |          | RANGE         | MEAN     |       |          | RANGE    | MEAN     |
| 10        | 0.075         | 0.008   | 0.060158 | 0.089844 | 0.029688 | 0.39584  |               | 0.119    | 0.004 | 0.106928 | 0.131072 | 0.024144 |
| 8         | 0.094         | 0.008   | 0.074208 | 0.113792 | 0.039584 | 0.421106 |               | 0.088    | 0.004 | 0.075928 | 0.100072 | 0.024144 |
| 3         | 0.065         | 0.008   | 0.045208 | 0.084792 | 0.039584 | 0.608985 |               | 0.097    | 0.005 | 0.08191  | 0.11209  | 0.03018  |
| 2         | 0.101         | 0.009   | 0.078734 | 0.123266 | 0.044532 | 0.440911 |               | 0.095    | 0.006 | 0.076892 | 0.113108 | 0.036216 |
| 7         | 0.16          | 0.009   | 0.137734 | 0.182266 | 0.044532 | 0.278325 |               | 0.141    | 0.006 | 0.122892 | 0.159108 | 0.036216 |
| 5         | 0.088         | 0.01    | 0.06326  | 0.11274  | 0.04948  | 0.562273 |               | 0.057    | 0.006 | 0.038892 | 0.075108 | 0.036216 |
| 1         | 0.099         | 0.01    | 0.07426  | 0.12374  | 0.04948  | 0.499798 |               | 0.107    | 0.006 | 0.088892 | 0.125108 | 0.036216 |
| 4         | 0.153         | 0.014   | 0.118364 | 0.167636 | 0.069272 | 0.452758 |               | 0.1      | 0.007 | 0.078874 | 0.121128 | 0.042252 |
| 9         | 0.087         | 0.014   | 0.052364 | 0.121638 | 0.069272 | 0.79623  |               | 0.104    | 0.008 | 0.079856 | 0.128144 | 0.048288 |
| 6         | 0.085         | 0.015   | 0.04769  | 0.12211  | 0.07422  | 0.873176 |               | 0.096    | 0.01  | 0.06582  | 0.12618  | 0.06036  |

Table XII. Initial Design Values; Tolerance Ranges

| COMPOSITE MATERIALS - MIN/MAX 90/95 TOLERANCE - ALL FOUR MATE |          |          |          |
|---|----------|----------|----------|
| SORT ON RANGE   |          |          |          |
| LUBRICANT   | MIN      | MAX      | RANGE    |
| 8   | 0.074208 | 0.13274  | 0.058532 |
| 10  | 0.060156 | 0.147636 | 0.08748  |
| 7   | 0.09463  | 0.182266 | 0.087636 |
| 1   | 0.072208 | 0.170532 | 0.098324 |
| 5   | 0.061156 | 0.161532 | 0.100376 |
| 2   | 0.06582  | 0.16948  | 0.10366  |
| 6   | 0.04789  | 0.152636 | 0.104746 |
| 3   | 0.03563  | 0.164902 | 0.129318 |
| 9   | 0.052364 | 0.255064 | 0.2027   |
| 4   | 0.118364 | 0.357752 | 0.023939 |

Table XIII. Used Stud Design Values; Tolerance Ranges

| 90%/95% TOLERANCE BANDS FOR COEFFICIENT OF FRICTION<br>USED STUD DESIGN VALUES |         |         |           |          |          |          |         |         |          | SORT ON RANGE |          |      |          |           |        |      |  |  |  |
|--|---------|---------|-----------|----------|----------|----------|---------|---------|----------|---------------|----------|------|----------|-----------|--------|------|--|--|--|
| LUBR.  | MEAN    | STD DEV | 90/95 TOL |          | 4140 PHO |          | RANGE/  |         | RANGE    | 90/95 TOL     |          | HIGH | RANGE    | LUBRICANT | RANGE/ | MEAN |  |  |  |
|  | INCONEL |         | LOW       | HIGH     | MEAN     | MEAN     | STD DEV | STD DEV |          | LOW           | HIGH     |      |          |           |        |      |  |  |  |
| 1  | 0.122   | 0.011   | 0.064766  | 0.149214 | 0.054428 | 0.446131 | 0.094   | 0.009   | 0.061734 | 0.106266      | 0.044532 | 1    | 0.530143 |           |        |      |  |  |  |
| 2  | 0.105   | 0.011   | 0.077766  | 0.132214 | 0.054428 | 0.518362 | 0.082   | 0.009   | 0.059734 | 0.104266      | 0.044532 | 2    | 0.543073 |           |        |      |  |  |  |
| 3  | 0.091   | 0.018   | 0.046468  | 0.135532 | 0.089084 | 0.978725 | 0.049   | 0.007   | 0.031682 | 0.066318      | 0.034636 | 3    | 0.706857 |           |        |      |  |  |  |
| 4  | N/A     | N/A     | 0         | 0        | 0        | 0        | 0.148   | 0.011   | 0.120786 | 0.175214      | 0.054428 | 4    | 0.367757 |           |        |      |  |  |  |
| 5  | 0.105   | 0.014   | 0.070364  | 0.139636 | 0.069272 | 0.659733 | 0.076   | 0.007   | 0.056682 | 0.093318      | 0.034636 | 5    | 0.455737 |           |        |      |  |  |  |
| 6  | 0.116   | 0.012   | 0.066312  | 0.145688 | 0.059376 | 0.511862 | 0.079   | 0.005   | 0.06663  | 0.09137       | 0.02474  | 6    | 0.313165 |           |        |      |  |  |  |
| 7  | 0.15    | 0.012   | 0.120312  | 0.179688 | 0.059376 | 0.39584  | 0.112   | 0.006   | 0.097156 | 0.126844      | 0.029688 | 7    | 0.265071 |           |        |      |  |  |  |
| 8  | 0.11    | 0.019   | 0.062994  | 0.157006 | 0.094012 | 0.854655 | 0.09    | 0.007   | 0.072682 | 0.107318      | 0.034636 | 8    | 0.384844 |           |        |      |  |  |  |
| 9  | 0.137   | 0.02    | 0.08752   | 0.18648  | 0.09896  | 0.722336 | 0.094   | 0.011   | 0.066786 | 0.121214      | 0.054428 | 9    | 0.579021 |           |        |      |  |  |  |
| 10   | 0.104   | 0.009   | 0.081734  | 0.126266 | 0.044532 | 0.428192 | 0.079   | 0.004   | 0.069104 | 0.088896      | 0.019792 | 10   | 0.250532 |           |        |      |  |  |  |

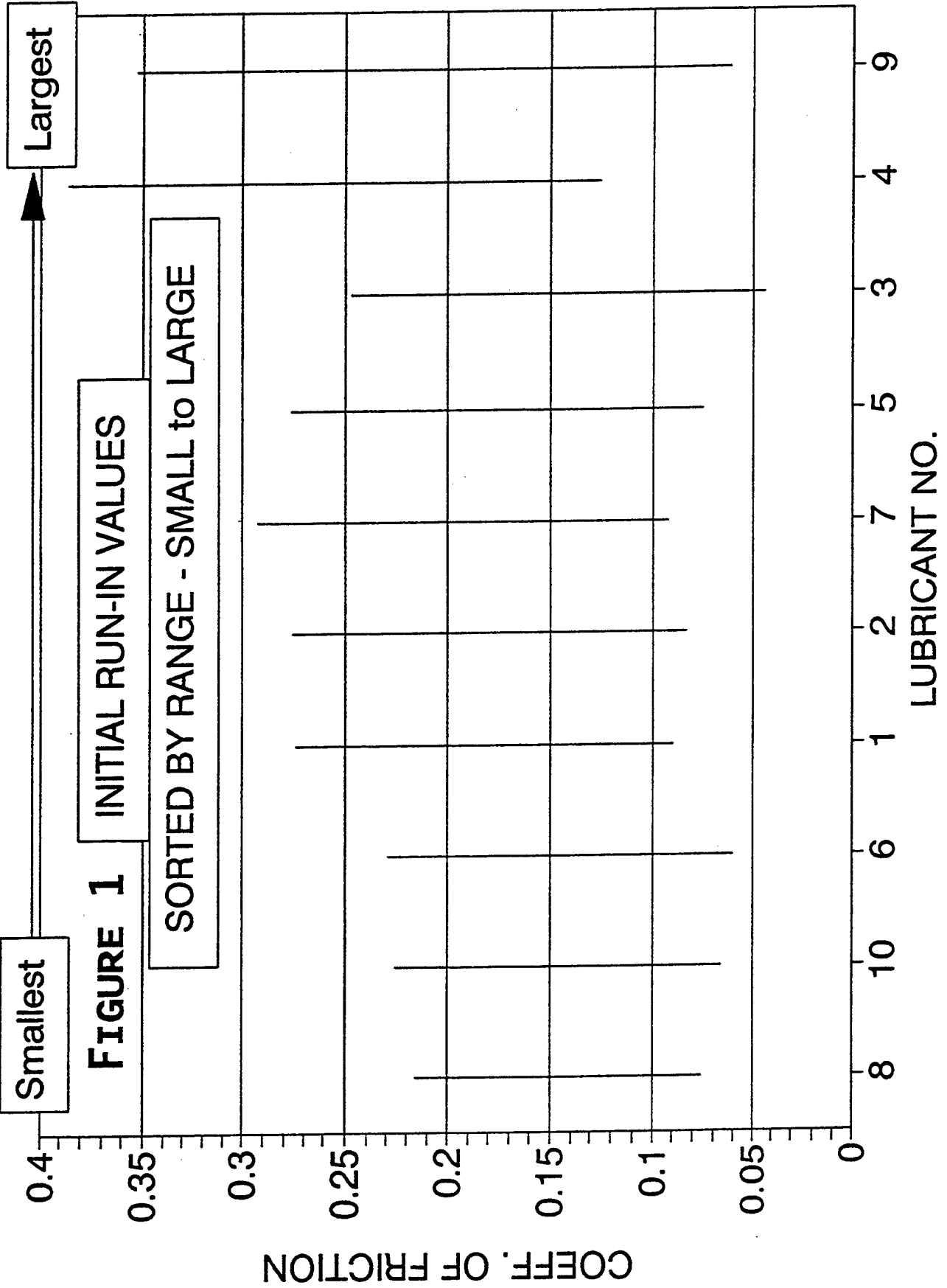
| 90/95 TOL |               |         |          |          |          |          |       |         |          | B7 ALLOY |          |       |           |        |      |  |  |  |  |
|-----------|---------------|---------|----------|----------|----------|----------|-------|---------|----------|----------|----------|-------|-----------|--------|------|--|--|--|--|
| LUBR.     | MEAN          | STD DEV | LOW      | HIGH     | RANGE/   |          | RANGE | STD DEV | HIGH     | RANGE/   |          | RANGE | LUBRICANT | RANGE/ | MEAN |  |  |  |  |
|           | K MONEL/MONEL |         |          |          | MEAN     | MEAN     |       |         |          | MEAN     | MEAN     |       |           |        |      |  |  |  |  |
| 1         | 0.095         | 0.011   | 0.067786 | 0.122214 | 0.054428 | 0.572926 | 0.096 | 0.004   | 0.063928 | 0.108072 | 0.024144 | 1     | 0.2515    |        |      |  |  |  |  |
| 2         | 0.098         | 0.012   | 0.068312 | 0.127688 | 0.059376 | 0.605978 | 0.088 | 0.009   | 0.060838 | 0.115162 | 0.054324 | 2     | 0.617318  |        |      |  |  |  |  |
| 3         | 0.057         | 0.006   | 0.042156 | 0.071844 | 0.029688 | 0.520842 | 0.052 | 0.005   | 0.03691  | 0.06709  | 0.03018  | 3     | 0.580385  |        |      |  |  |  |  |
| 4         | 0.176         | 0.013   | 0.143838 | 0.208162 | 0.064324 | 0.365477 | 0.149 | 0.005   | 0.13391  | 0.16409  | 0.03018  | 4     | 0.20255   |        |      |  |  |  |  |
| 5         | 0.083         | 0.007   | 0.065682 | 0.100318 | 0.034636 | 0.417301 | 0.087 | 0.007   | 0.065874 | 0.108126 | 0.042252 | 5     | 0.485655  |        |      |  |  |  |  |
| 6         | 0.077         | 0.009   | 0.054734 | 0.099266 | 0.044532 | 0.578338 | 0.103 | 0.011   | 0.069802 | 0.136198 | 0.066396 | 6     | 0.644621  |        |      |  |  |  |  |
| 7         | 0.153         | 0.006   | 0.138156 | 0.167844 | 0.029688 | 0.194039 | 0.121 | 0.004   | 0.108928 | 0.133072 | 0.024144 | 7     | 0.199537  |        |      |  |  |  |  |
| 8         | 0.094         | 0.01    | 0.06926  | 0.11874  | 0.04948  | 0.526383 | 0.1   | 0.004   | 0.087928 | 0.112072 | 0.024144 | 8     | 0.24144   |        |      |  |  |  |  |
| 9         | 0.085         | 0.013   | 0.052838 | 0.117162 | 0.064324 | 0.756753 | 0.086 | 0.011   | 0.052802 | 0.119198 | 0.066396 | 9     | 0.772047  |        |      |  |  |  |  |
| 10        | 0.075         | 0.006   | 0.060156 | 0.089844 | 0.029688 | 0.39584  | 0.084 | 0.003   | 0.074946 | 0.093054 | 0.018108 | 10    | 0.215571  |        |      |  |  |  |  |

Table XIV. Used Stud Design Values; Tolerance Ranges

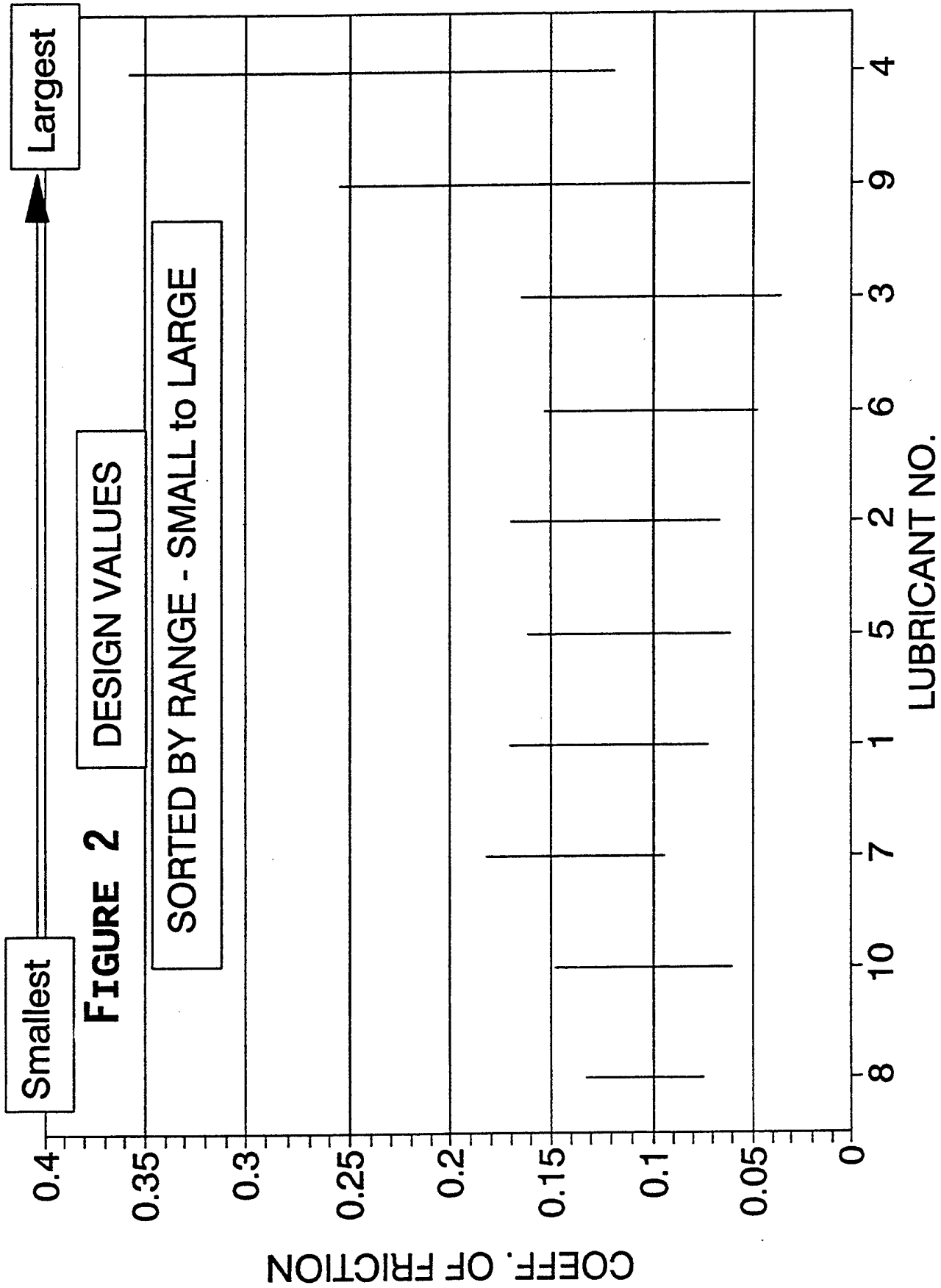
COMPOSITE MATERIALS - MIN/MAX 90/95 TOLERANCE - ALL FOUR MATERIALS

| LUBRICANT | SORT ON RANGE |          |          |
|-----------|---------------|----------|----------|
|           | MIN           | MAX      | RANGE    |
| 4         | n/a           | n/a      | n/a      |
| 10        | 0.060156      | 0.126266 | 0.06611  |
| 2         | 0.059734      | 0.132214 | 0.07248  |
| 5         | 0.058682      | 0.139636 | 0.080954 |
| 7         | 0.097156      | 0.179688 | 0.082532 |
| 1         | 0.061734      | 0.149214 | 0.08748  |
| 6         | 0.054734      | 0.145688 | 0.090954 |
| 8         | 0.062994      | 0.157006 | 0.094012 |
| 3         | 0.031682      | 0.135532 | 0.10385  |
| 9         | 0.052802      | 0.018648 | 0.133678 |

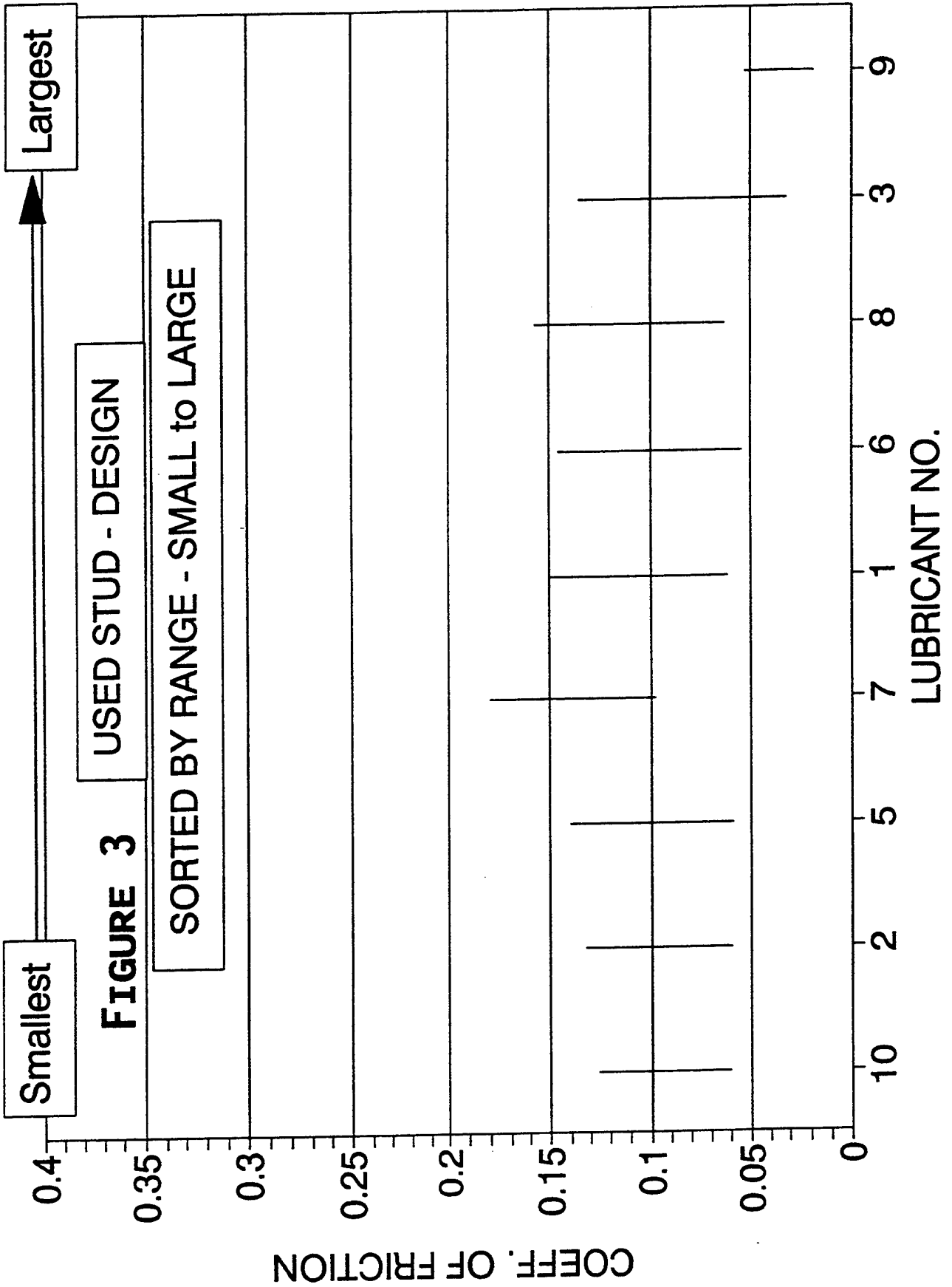
# COMPOSITE - 4 MAT'S



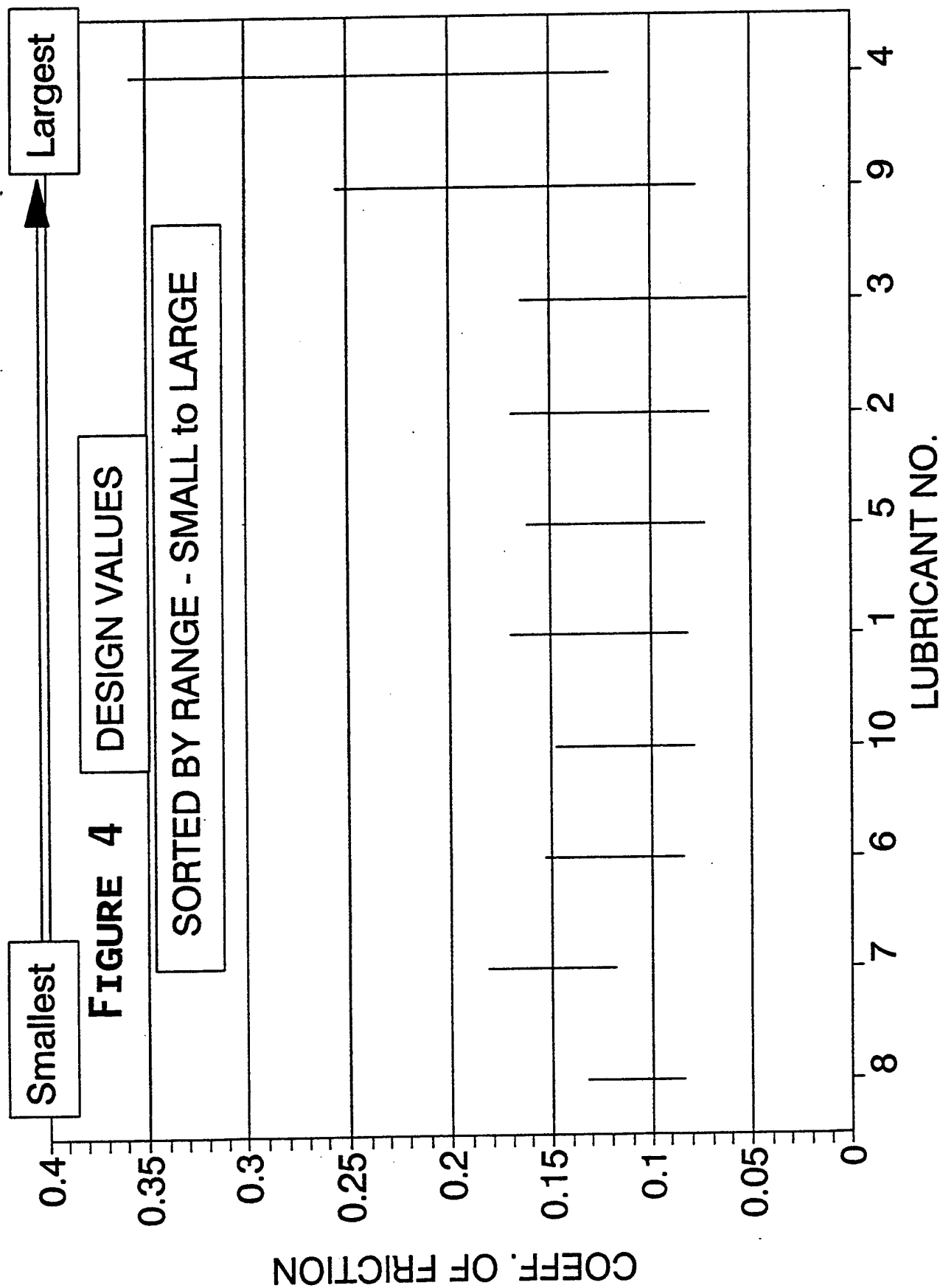
# COMPOSITE-4 MAT'S



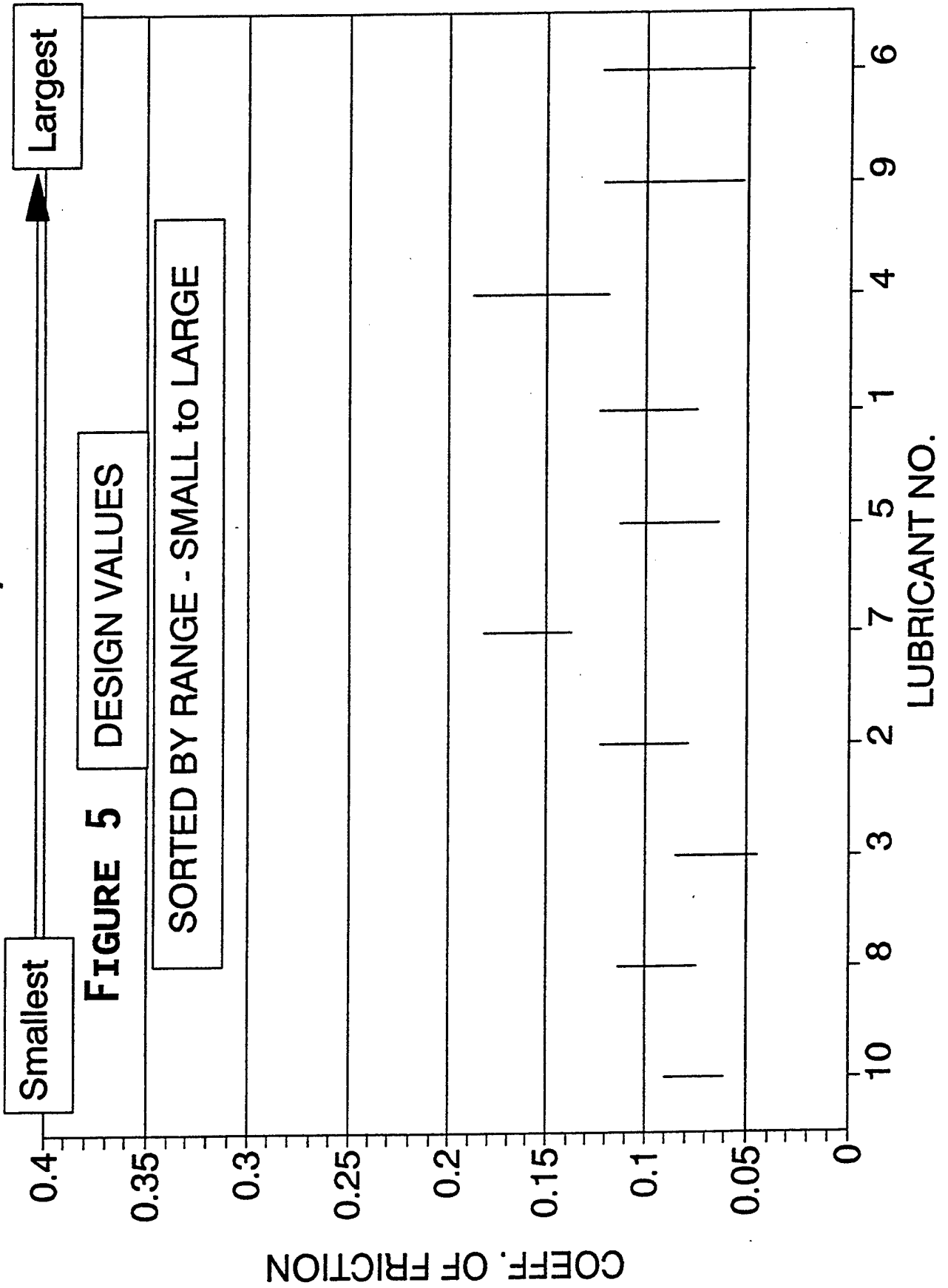
# COMPOSITE - 4 MAT'S



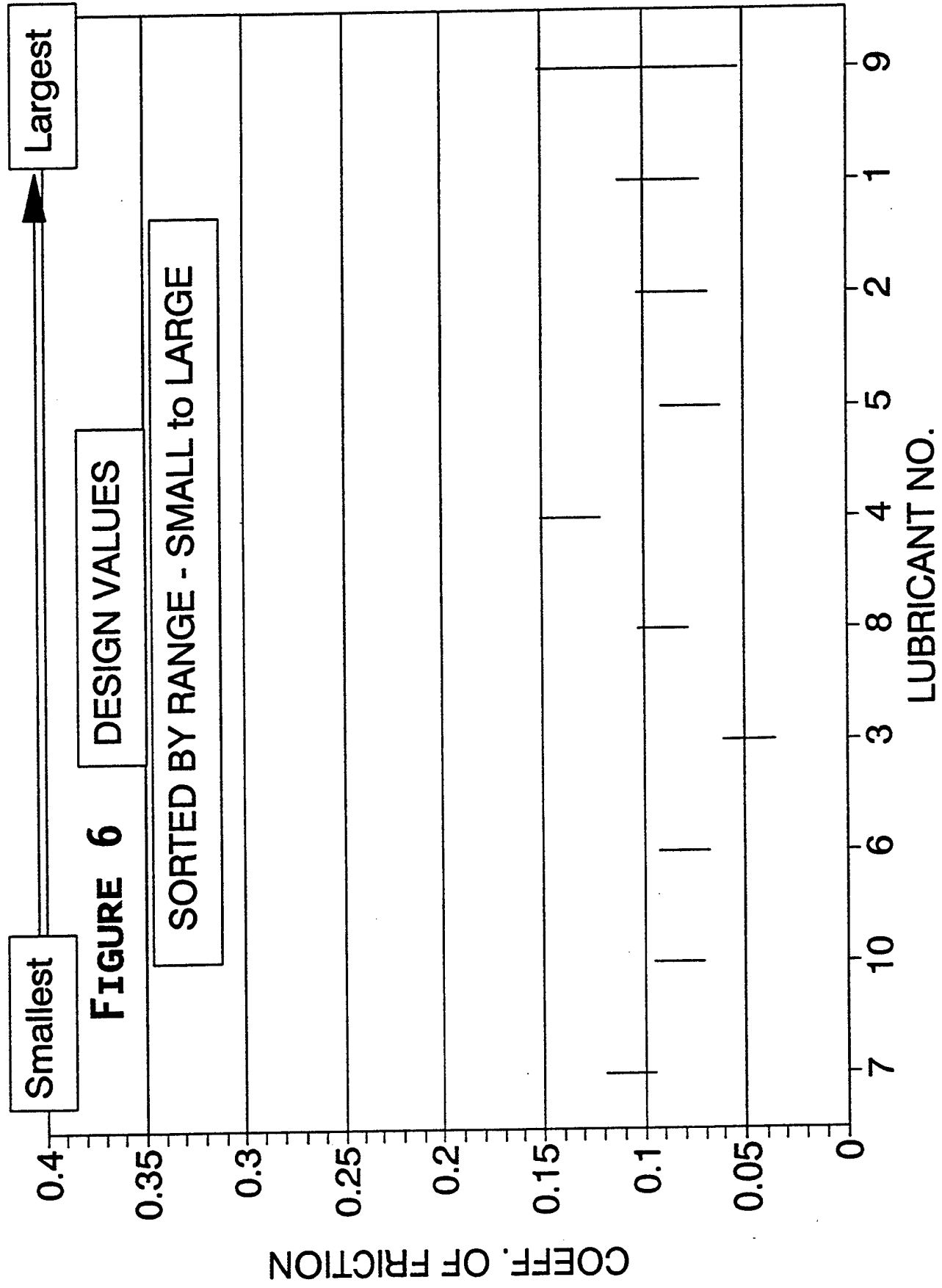
# INCONEL



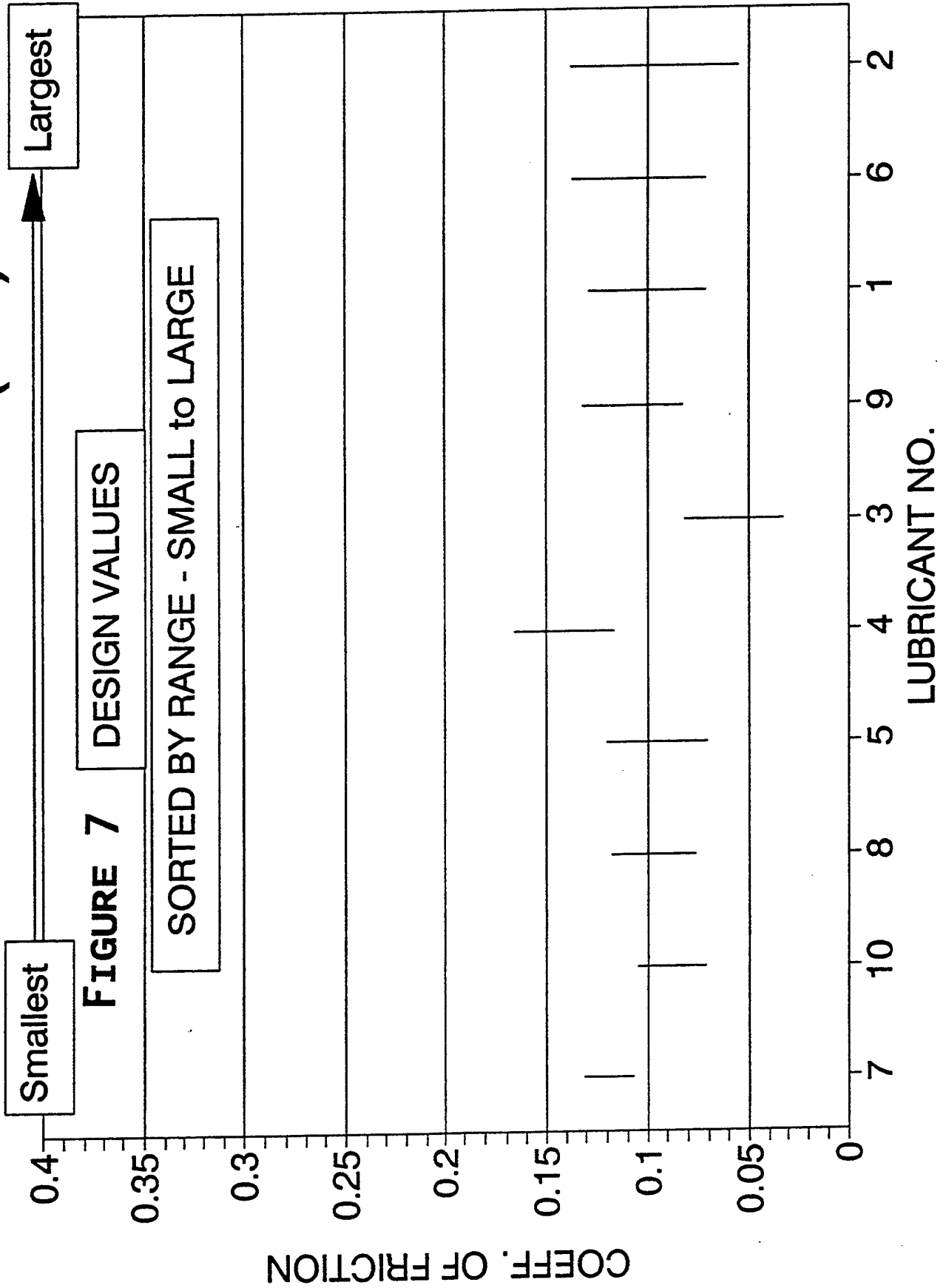
# K MONEL/MONEL



# AISI 4140 PHOSPHATE



# ALLOY STEEL (B7)



## **ATTACHMENT I**

### **Phase I - Coefficient of Friction Dataset**

#### **Alloy 625**

The main body of the following tables list each individual calculated coefficient of friction value, based on the equation of Appendix A, for every Alloy 625 stud tested. The mean coefficient of friction and standard deviations for each individual stud is provided at the bottom of the table, while the mean coefficient of friction, standard deviation and the results of the statistical tests performed for all studs tested under the same loading sequence are provided to the right of the individual values.

Table 1 Summary Statistics for I1

| STUD1    | STUD2    | STUD3    | STUD4    | STUD5    | MEAN<br>VALUE                | STD<br>DEVIATION | TEST<br>FOR<br>MEAN<br>t-TEST<br>t* = 1.68 | TEST<br>FOR<br>VARIANCE<br>F-TEST<br>F* = 1.98 | 95% Conf |
|----------|----------|----------|----------|----------|------------------------------|------------------|--|--|----------|
| 0.206176 | 0.256768 | 0.276194 | 0.178885 | 0.182788 |                              |                  |  |  |          |
| 0.18079  | 0.226041 | 0.249612 | 0.159115 | 0.184729 |                              |                  |  |  |          |
| 0.176099 | 0.215795 | 0.225959 | 0.157524 | 0.201812 | RUN-IN                       | 0.199813         | 0.029919                                   |  |          |
| 0.174479 | 0.193363 | 0.197991 | 0.190586 | 0.222039 |                              |                  |  |  |          |
| 0.171377 | 0.185481 | 0.19643  | 0.175111 | 0.205186 | XXXXXXXXXXXXXXXXXXXXXXXXXXXX |                  |  |  |          |
| 0.12811  | 0.163275 | 0.171081 | 0.10072  | 0.139838 |                              |                  |  |  |          |
| 0.109772 | 0.123599 | 0.139391 | 0.095936 | 0.125574 |                              |                  |  |  |          |
| 0.112347 | 0.118997 | 0.133619 | 0.105696 | 0.121656 | DESIGN                       | 0.126179         | 0.017637                                   | DESIGN VS RUN-IN<br>t<br>F                     | 2.877566 |
| 0.118657 | 0.110578 | 0.141584 | 0.119687 | 0.127742 |                              |                  |  | YES  | YES      |
| 0.128863 | 0.11324  | 0.142914 | 0.125739 | 0.135889 | XXXXXXXXXXXXXXXXXXXXXXXXXXXX |                  |  |  |          |
| 0.167178 | 0.171081 | 0.182788 | 0.12811  | 0.151559 |                              |                  |  |  |          |
| 0.141365 | 0.159115 | 0.166999 | 0.133471 | 0.155172 | USED STUD RUN-IN             |                  |  |  |          |
| 0.145575 | 0.162833 | 0.169467 | 0.137605 | 0.173446 |                              | 0.154424         | 0.014373                                   |  |          |
| 0.14352  | 0.154167 | 0.159973 | 0.145457 | 0.175446 |                              |                  |  |  |          |
| 0.13745  | 0.14597  | 0.148213 | 0.144474 | 0.160172 | XXXXXXXXXXXXXXXXXXXXXXXXXXXX |                  |  |  |          |
| 0.108549 | 0.147653 | ERR      | 0.116375 | 0.143746 |                              |                  |  |  |          |
| 0.101867 | 0.127549 | ERR      | 0.111748 | 0.129523 | USED STUD DESIGN             |                  |  | DESIGN VS USED STUD DESIGN<br>t<br>F           | 2.696523 |
| 0.109687 | 0.118997 | ERR      | 0.117667 | 0.130961 |                              | 0.121656         | 0.010741                                   | 1.059955                                       | NO       |
| 0.118657 | 0.117647 | ERR      | 0.117647 | 0.128733 |                              |                  |  | YES  | YES      |
| 0.124958 | 0.121834 | ERR      | 0.117147 | 0.124177 | XXXXXXXXXXXXXXXXXXXXXXXXXXXX |                  |  |  |          |
|          |          |          |          |          | OVERALL                      |                  |  |  |          |
| MEAN     | 0.140274 | 0.156699 | 0.180147 | 0.133934 | 0.152                        | 0.037            |  |  |          |
| STD DEV  | 0.029683 | 0.041377 | 0.042456 | 0.026789 | 0.03083                      |                  |  |  |          |

TABLE 2: A TABLE2; ALLOY TYPE I, LUBRICANT NO.2

| STUD1    | STUD2    | STUD3    | STUD4    | STUD5    | MEAN<br>VALUE           | STD<br>DEVIATION | TEST<br>FOR<br>MEAN<br>t-TEST<br>t* = 1.88 | TEST<br>FOR<br>VARIANCE<br>F-TEST<br>F* = 1.98 | 95% Confl |
|----------|----------|----------|----------|----------|-------------------------|------------------|--|--|-----------|
| 0.31901  | 0.186768 | 0.171157 | 0.256881 | 0.217958 |                         |                  |  |  |           |
| 0.222208 | 0.172987 | 0.16313  | 0.208437 | 0.18284  |                         |                  |  |  |           |
| 0.198084 | 0.17485  | 0.17485  | 0.190448 | 0.176177 | RUN-IN                  | 0.188993         | 0.035414                                   |  |           |
| 0.183259 | 0.177457 | 0.173589 | 0.179392 | 0.161979 |                         |                  |  |  |           |
| 0.172947 | 0.167717 | 0.165475 | 0.168464 | 0.15127  | XXXXXXXXXXXXXXXXXXXXXXX |                  |  |  |           |
| 0.19847  | 0.108597 | 0.116427 | 0.104681 | 0.120341 |                         |                  |  |  |           |
| 0.135504 | 0.094    | 0.105887 | 0.101912 | 0.101912 |                         |                  |  |  |           |
| 0.116389 | 0.109735 | 0.112397 | 0.12171  | 0.112397 | DESIGN                  | 0.119887         | 0.01962                                    | 8.497643                                       | 3.258124  |
| 0.110627 | 0.12073  | 0.11871  | 0.133856 | 0.117699 |                         |                  |  |  |           |
| 0.123451 | 0.125014 | 0.132826 | 0.134388 | 0.119544 | XXXXXXXXXXXXXXXXXXXXXXX |                  |  |  |           |
| 0.186768 | 0.1399   | 0.128186 | 0.159441 | 0.124254 |                         |                  |  |  |           |
| 0.141427 | 0.121679 | 0.12563  | 0.137479 | 0.10389  | USED STUD RUN-IN        |                  |  |  |           |
| 0.14431  | 0.12171  | 0.132348 | 0.142982 | 0.108405 |                         | 0.132888         | 0.017871                                   |  |           |
| 0.134865 | 0.124769 | 0.134865 | 0.148428 | 0.107596 |                         |                  |  |  |           |
| 0.130482 | 0.127358 | 0.132826 | 0.149028 | 0.1086   | XXXXXXXXXXXXXXXXXXXXXXX |                  |  |  |           |
| 0.128166 | 0.092929 | 0.092929 | 0.108597 | 0.104681 |                         |                  |  |  |           |
| 0.105867 | 0.092022 | 0.094    | 0.101912 | 0.088065 | USED STUD DESIGN        |                  |  |  |           |
| 0.113728 | 0.097754 | 0.097754 | 0.108405 | 0.092427 |                         | 0.105054         | 0.01073                                    | 3.316556                                       | 3.343545  |
| 0.12073  | 0.104564 | 0.102542 | 0.11871  | 0.098476 |                         |                  |  |  |           |
| 0.116417 | 0.110945 | 0.105472 | 0.121888 | 0.109381 | XXXXXXXXXXXXXXXXXXXXXXX |                  |  |  |           |
|          |          |          |          |          | OVERALL                 |                  |  |  |           |
| MEAN     | 0.155136 | 0.128574 | 0.139217 | 0.144852 |                         | 0.136581         | 0.038906                                   |  |           |
| STD DEV  | 0.051775 | 0.030889 | 0.023843 | 0.040161 |                         |                  |  |  |           |

TABLE 3: ALLOY TYPE I, LUBRICANT NO. 3

| STUD1    | STUD2    | STUD3    | STUD4    | STUD5    | MEAN<br>VALUE           | STD<br>DEVIATION | TEST<br>FOR |                  | TEST<br>FOR<br>VARIANCE |
|----------|----------|----------|----------|----------|-------------------------|------------------|-------------|------------------|-------------------------|
|          |          |          |          |          |                         |                  | t-TEST      | F-TEST           |                         |
| 0.237428 | 0.175061 | 0.19847  | 0.229642 | 0.167252 |                         |                  | t* = 1.68   | F* = 1.98        | 95% Confl               |
| 0.220241 | 0.159185 | 0.202533 | 0.208437 | 0.151295 |                         |                  |             |                  |                         |
| 0.203173 | 0.158922 | 0.208261 | 0.190448 | 0.168215 | RUN-IN                  | 0.164714         | 0.025132    |                  |                         |
| 0.174556 | 0.173589 | 0.205484 | 0.163914 | 0.171654 |                         |                  |             |                  |                         |
| 0.155757 | 0.176176 | 0.200167 | 0.148278 | 0.167717 | XXXXXXXXXXXXXXXXXXXXXXX |                  |             |                  |                         |
| 0.120341 | 0.100764 | 0.159441 | 0.08509  | 0.08117  |                         |                  |             |                  |                         |
| 0.101912 | 0.080148 | 0.139453 | 0.082128 | 0.080148 |                         |                  |             |                  |                         |
| 0.113728 | 0.087099 | 0.140324 | 0.084434 | 0.087099 | DESIGN                  | 0.107506         | 0.023478    | DESIGN VS RUN-IN |                         |
| 0.110627 | 0.116689 | 0.144553 | 0.089397 | 0.093443 |                         |                  | t           | F                |                         |
| 0.109381 | 0.127358 | 0.138292 | 0.099769 | 0.114854 | XXXXXXXXXXXXXXXXXXXXXXX |                  | 11.22467    | 1.14594          | YES NO                  |
| 0.108597 | 0.08117  | 0.175061 | 0.092929 | 0.124254 |                         |                  |             |                  |                         |
| 0.113774 | 0.086086 | 0.159185 | 0.084107 | 0.13353  | USED STUD RUN-IN        |                  |             |                  |                         |
| 0.129689 | 0.105742 | 0.152281 | 0.081769 | 0.145639 |                         | 0.119836         | 0.027632    |                  |                         |
| 0.128808 | 0.113659 | 0.139709 | 0.080292 | 0.150363 |                         |                  |             |                  |                         |
| 0.121107 | 0.109381 | 0.13595  | 0.090804 | 0.152018 | XXXXXXXXXXXXXXXXXXXXXXX |                  |             |                  |                         |
| 0.073328 | 0.069405 | 0.132078 | 0.073328 | 0.08117  |                         |                  |             |                  |                         |
| 0.066287 | 0.070248 | 0.105867 | 0.064306 | 0.076189 | USED STUD DESIGN        |                  | t           | F                |                         |
| 0.088431 | 0.079104 | 0.100417 | 0.077771 | 0.084434 |                         | 0.091014         | 0.018451    | 2.761431         | 1.619091                |
| 0.094454 | 0.086363 | 0.114669 | 0.103553 | 0.095465 |                         |                  | YES         | NO               |                         |
| 0.109381 | 0.092434 | 0.12267  | 0.110163 | 0.103842 | XXXXXXXXXXXXXXXXXXXXXXX |                  |             |                  |                         |
|          |          |          |          |          | OVERALL                 |                  |             |                  |                         |
| MEAN     | 0.12905  | 0.112529 | 0.166611 | 0.112028 | 0.125768                | 0.042778         |             |                  |                         |
| STD DEV  | 0.046513 | 0.03695  | 0.028587 | 0.046595 | 0.035324                |                  |             |                  |                         |

TABLE 4: ALLOY I, LUBRICANT NO. 4

| TABLE 4: ALLOY I, LUBRICANT NO. 4 |                              |          |          |          |          |                              |                  |                     |                         |   |          |
|-----------------------------------|------------------------------|----------|----------|----------|----------|------------------------------|------------------|---------------------|-------------------------|---|----------|
|                                   | STUD1                        | STUD2    | STUD3    | STUD4    | STUD5    | MEAN<br>VALUE                | STD<br>DEVIATION | TEST<br>FOR<br>MEAN | TEST<br>FOR<br>VARIANCE |   |          |
|                                   | 0.307375                     | 0.276316 | 0.249102 | 0.276316 | 0.419584 |                              |                  | t-TEST              | F-TEST                  |   |          |
|                                   | 0.282827                     | 0.279182 | 0.257576 | 0.257576 | 0.348837 |                              |                  | t* =1.68            | F* =1.98                |   | 95% Conf |
|                                   | 0.260976                     | 0.276776 | 0.279206 | 0.241303 | 0.340332 | RUN-IN                       | 0.287076         | 0.040144            |                         |   |          |
|                                   | 0.284333                     | 0.308375 | 0.316063 | 0.257553 | 0.315102 |                              |                  |                     |                         |   |          |
|                                   | 0.288956                     | 0.288956 | 0.273911 | 0.219964 | 0.272327 | XXXXXXXXXXXXXXXXXXXXXXXXXXXX |                  |                     |                         |   |          |
|                                   | 0.225748                     | 0.252992 | 0.342262 | 0.167252 | 0.24132  |                              |                  |                     |                         |   |          |
|                                   | 0.202533                     | 0.234004 | 0.307386 | 0.159185 | 0.239899 |                              |                  | DESIGN VS RUN-IN    |                         |   |          |
|                                   | 0.21589                      | 0.2286   | 0.313061 | 0.172196 | 0.250031 | DESIGN                       | 0.238642         | 0.048284            | t                       | F |          |
|                                   | 0.250326                     | 0.263875 | 0.287219 | 0.175523 | 0.25936  |                              |                  | 3.856715            | 1.446634                |   |          |
|                                   | 0.218408                     | 0.233962 | 0.29934  | 0.169959 | 0.255717 | XXXXXXXXXXXXXXXXXXXXXXXXXXXX |                  | YES                 | NO                      |   |          |
|                                   | USED STUD RUN-IN             |          |          |          |          |                              | 0                | 0                   |                         |   |          |
|                                   | XXXXXXXXXXXXXXXXXXXXXXXXXXXX |          |          |          |          |                              |                  |                     |                         |   |          |
|                                   | DESIGN VS USED STUD DESIGN   |          |          |          |          |                              |                  | t                   | F                       |   |          |
|                                   | USED STUD DESIGN             |          |          |          |          |                              | 0                | 0                   |                         |   |          |
|                                   | XXXXXXXXXXXXXXXXXXXXXXXXXXXX |          |          |          |          |                              |                  |                     |                         |   |          |
|                                   | OVERALL                      |          |          |          |          |                              | 0.262859         | 0.050295            |                         |   |          |
| MEAN                              | 0.126874                     | 0.132151 | 0.195008 | 0.104841 | 0.147026 |                              |                  |                     |                         |   |          |
| STD DEV                           | 0.132584                     | 0.136804 | 0.144565 | 0.11203  | 0.156315 |                              |                  |                     |                         |   |          |

TABLE 5: ALLOY I, LUBRICANT NO. 5

| STUD1    | STUD2    | STUD3    | STUD4    | STUD5    | MEAN<br>VALUE           | STD<br>DEVIATION | TEST<br>FOR<br>MEAN | TEST<br>FOR<br>VARIANCE         | TEST<br>F-TEST<br>F*=1.98 | 95% Conf |
|----------|----------|----------|----------|----------|-------------------------|------------------|---------------------|---------------------------------|---------------------------|----------|
| 0.163347 | 0.276316 | 0.19457  | 0.225748 | 0.252892 |                         |                  |                     |                                 |                           |          |
| 0.153268 | 0.251686 | 0.172987 | 0.208437 | 0.210405 |                         |                  |                     |                                 |                           |          |
| 0.169542 | 0.236223 | 0.172196 | 0.203173 | 0.206989 | RUN-IN                  | 0.196735         | 0.032197            |                                 |                           |          |
| 0.163914 | 0.206409 | 0.175523 | 0.193448 | 0.201781 |                         |                  |                     |                                 |                           |          |
| 0.155757 | 0.187024 | 0.167717 | 0.183372 | 0.185563 | XXXXXXXXXXXXXXXXXXXXXXX |                  |                     |                                 |                           |          |
| 0.120341 | 0.159441 | 0.08509  | 0.128166 | 0.120341 |                         |                  |                     |                                 |                           |          |
| 0.101912 | 0.12563  | 0.092022 | 0.13353  | 0.10389  |                         |                  |                     |                                 |                           |          |
| 0.105742 | 0.116389 | 0.096423 | 0.146988 | 0.105742 | DESIGN                  | 0.117324         | 0.018045            | DESIGN VS RUN-IN<br>t           | F                         | 3.183422 |
| 0.107596 | 0.110627 | 0.103553 | 0.143584 | 0.116689 |                         |                  |                     | YES                             | YES                       |          |
| 0.107036 | 0.119544 | 0.116417 | 0.144538 | 0.121888 | XXXXXXXXXXXXXXXXXXXXXXX |                  |                     |                                 |                           |          |
| 0.096847 | 0.214062 | 0.100764 | 0.120341 | 0.178964 |                         |                  |                     |                                 |                           |          |
| 0.105867 | 0.161158 | 0.095979 | 0.117727 | 0.159185 | USED STUD RUN-IN        |                  |                     |                                 |                           |          |
| 0.12171  | 0.156266 | 0.10308  | 0.129689 | 0.160249 |                         | 0.134821         | 0.028662            |                                 |                           |          |
| 0.132846 | 0.153268 | 0.103553 | 0.129818 | 0.153268 |                         |                  |                     |                                 |                           |          |
| 0.133607 | 0.150522 | 0.114072 | 0.130482 | 0.142196 | XXXXXXXXXXXXXXXXXXXXXXX |                  |                     |                                 |                           |          |
| 0.08117  | 0.1399   | 0.08901  | 0.100764 | 0.1399   |                         |                  |                     |                                 |                           |          |
| 0.086086 | 0.111798 | 0.088065 | 0.105867 | 0.113774 | USED STUD DESIGN        |                  |                     |                                 |                           |          |
| 0.089763 | 0.113728 | 0.095091 | 0.105742 | 0.111066 |                         | 0.10534          | 0.014429            | DESIGN VS USED STUD DESIGN<br>t | F                         | 1.564176 |
| 0.095465 | 0.112648 | 0.096476 | 0.112648 | 0.106585 |                         |                  |                     | YES                             | NO                        |          |
| 0.103028 | 0.113291 | 0.098954 | 0.115638 | 0.107036 | XXXXXXXXXXXXXXXXXXXXXXX |                  |                     |                                 |                           |          |
|          |          |          |          |          | OVERALL                 |                  |                     |                                 |                           |          |
| MEAN     | 0.119742 | 0.160796 | 0.126283 | 0.143984 | 0.138505                | 0.04279          |                     |                                 |                           |          |
| STD DEV  | 0.028144 | 0.051371 | 0.038028 | 0.037777 | 0.043574                |                  |                     |                                 |                           |          |

TABLE 6: ALLOY 1, LUBRICANT NO. 6

| STUD1    | STUD2    | STUD3    | STUD4    | STUD5    | MEAN<br>VALUE        | STD<br>DEVIATION | TEST<br>FOR<br>MEAN | TEST<br>FOR<br>VARIANCE         | F-TEST<br>F*=1.98 | 95% Confi |
|----------|----------|----------|----------|----------|----------------------|------------------|---------------------|---------------------------------|-------------------|-----------|
| 0.217958 | 0.19457  | 0.210165 | 0.210165 | 0.182867 |                      |                  |                     |                                 |                   |           |
| 0.204501 | 0.1769   | 0.172987 | 0.202533 | 0.157213 |                      |                  |                     |                                 |                   |           |
| 0.200629 | 0.187902 | 0.18281  | 0.187902 | 0.169922 | RUN-IN               | 0.184678         | 0.017745            |                                 |                   |           |
| 0.192522 | 0.185112 | 0.192522 | 0.178425 | 0.155204 |                      |                  |                     |                                 |                   |           |
| 0.181911 | 0.173694 | 0.185563 | 0.170706 | 0.15127  | XXXXXXXXXXXXXXXXXXXX |                  |                     |                                 |                   |           |
| 0.112512 | 0.120341 | 0.120341 | 0.135989 | 0.128166 |                      |                  |                     |                                 |                   |           |
| 0.097957 | 0.10389  | 0.10389  | 0.121679 | 0.105867 |                      |                  |                     |                                 |                   |           |
| 0.099086 | 0.111066 | 0.111066 | 0.12836  | 0.116389 | DESIGN               | 0.116394         | 0.013559            | DESIGN VS RUN-IN<br>t           | 1.71283           |           |
| 0.103553 | 0.107596 | 0.139709 | 0.133856 | 0.11972  |                      |                  |                     | YES                             | NO                |           |
| 0.116417 | 0.113291 | 0.15127  | 0.131263 | 0.126576 | XXXXXXXXXXXXXXXXXXXX |                  |                     |                                 |                   |           |
| 0.19457  | 0.15534  | 0.182867 | 0.147718 | 0.19457  |                      |                  |                     |                                 |                   |           |
| 0.167073 | 0.141427 | 0.143401 | 0.151295 | 0.165102 | USED STUD RUN-IN     |                  |                     |                                 |                   |           |
| 0.162905 | 0.146968 | 0.136336 | 0.152281 | 0.156266 |                      | 0.152594         | 0.017024            |                                 |                   |           |
| 0.151331 | 0.147458 | 0.137772 | 0.144553 | 0.145521 |                      |                  |                     |                                 |                   |           |
| 0.144538 | 0.134388 | 0.13673  | 0.13673  | 0.137511 | XXXXXXXXXXXXXXXXXXXX |                  |                     |                                 |                   |           |
| 0.1399   | 0.100764 | 0.147718 | 0.104681 | 0.124254 |                      |                  |                     |                                 |                   |           |
| 0.117727 | 0.095979 | 0.115751 | 0.097957 | 0.111798 | USED STUD DESIGN     |                  |                     | DESIGN VS USED STUD DESIGN<br>t | F                 |           |
| 0.116389 | 0.115058 | 0.111066 | 0.10308  | 0.117719 |                      | 0.116017         | 0.012363            | -0.64757                        | 1.202809          |           |
| 0.109617 | 0.129818 | 0.11871  | 0.107596 | 0.11871  |                      |                  |                     | NO                              | NO                |           |
| 0.110945 | 0.133607 | 0.121886 | 0.110945 | 0.116762 | XXXXXXXXXXXXXXXXXXXX |                  |                     |                                 |                   |           |
|          |          |          |          |          | OVERALL              |                  |                     |                                 |                   |           |
| MEAN     | 0.147102 | 0.138868 | 0.153829 | 0.142886 |                      | 0.142921         | 0.032045            |                                 |                   |           |
| STD DEV  | 0.040202 | 0.031493 | 0.032008 | 0.032946 |                      |                  |                     |                                 |                   |           |

TABLE 7: ALLOY I, LUBRICANT NO.7

| STUD1    | STUD2    | STUD3    | STUD4    | STUD5    | MEAN<br>VALUE        | STD<br>DEVIATION | TEST<br>FOR<br>MEAN | TEST<br>FOR<br>VARIANCE | F-TEST<br>F*=1.98 | 95% Conf |
|----------|----------|----------|----------|----------|----------------------|------------------|---------------------|-------------------------|-------------------|----------|
| 0.237428 | 0.202389 | 0.276316 | 0.276316 | 0.295733 |                      |                  |                     |                         |                   |          |
| 0.220241 | 0.230072 | 0.251686 | 0.255613 | 0.234004 |                      |                  |                     |                         |                   |          |
| 0.22733  | 0.222246 | 0.246381 | 0.238763 | 0.219704 | RUN-IN               | 0.231141         | 0.025372            | t-TEST<br>t*=1.68       |                   |          |
| 0.220288 | 0.215663 | 0.231344 | 0.211962 | 0.210111 |                      |                  |                     |                         |                   |          |
| 0.211114 | 0.200897 | 0.244065 | 0.197977 | 0.200897 | XXXXXXXXXXXXXXXXXXXX |                  |                     |                         |                   |          |
| 0.1399   | 0.186768 | 0.171157 | 0.171157 | 0.171157 |                      |                  |                     |                         |                   |          |
| 0.143401 | 0.149321 | 0.143401 | 0.13353  | 0.141427 |                      |                  |                     |                         |                   |          |
| 0.140324 | 0.15361  | 0.138995 | 0.138995 | 0.140324 | DESIGN               | 0.1503           | 0.013272            | t<br>F                  | 14.11643          | 3.654582 |
| 0.154236 | 0.158108 | 0.141647 | 0.144553 | 0.137772 |                      |                  |                     | YES                     | YES               |          |
| 0.155757 | 0.159495 | 0.146782 | 0.154281 | 0.141415 | XXXXXXXXXXXXXXXXXXXX |                  |                     |                         |                   |          |
| 0.167252 | 0.182867 | 0.178964 | 0.163347 | 0.162867 |                      |                  |                     |                         |                   |          |
| 0.161158 | 0.15524  | 0.159185 | 0.161158 | 0.16313  | USED STUD RUN-IN     |                  |                     |                         |                   |          |
| 0.172196 | 0.156266 | 0.162905 | 0.164232 | 0.161577 | 0.165445             | 0.007008         |                     |                         |                   |          |
| 0.166817 | 0.162947 | 0.164882 | 0.167785 | 0.162947 |                      |                  |                     |                         |                   |          |
| 0.16398  | 0.16398  | 0.165475 | 0.163232 | 0.161738 | XXXXXXXXXXXXXXXXXXXX |                  |                     |                         |                   |          |
| 0.1399   | 0.151626 | 0.151626 | 0.143809 | 0.178964 |                      |                  |                     |                         |                   |          |
| 0.131555 | 0.131555 | 0.139453 | 0.153268 | 0.157213 | USED STUD DESIGN     |                  |                     |                         |                   |          |
| 0.136336 | 0.146968 | 0.140324 | 0.160249 | 0.152281 | 0.14973              | 0.011608         |                     | t<br>F                  | -0.16146          | 1.307768 |
| 0.140678 | 0.154236 | 0.140678 | 0.16585  | 0.156172 |                      |                  |                     | NO                      | NO                |          |
| 0.143757 | 0.163232 | 0.144638 | 0.166222 | 0.152766 | XXXXXXXXXXXXXXXXXXXX |                  |                     |                         |                   |          |
|          |          |          |          |          | OVERALL              |                  |                     |                         |                   |          |
| MEAN     | 0.168882 | 0.172373 | 0.188212 | 0.176814 | 0.174154             | 0.037108         |                     |                         |                   |          |
| STD DEV  | 0.034557 | 0.027948 | 0.047352 | 0.039414 | 0.039189             |                  |                     |                         |                   |          |

TABLE 8: ALLOY I, LUBRICANT NO. 8

| STUD1    | STUD2    | STUD3    | STUD4    | STUD5    | MEAN<br>VALUE           | STD<br>DEVIATION | TEST<br>FOR<br>MEAN<br>t-TEST<br>t* = 1.68 | TEST<br>FOR<br>VARIANCE<br>F-TEST<br>F* = 1.98 | 95% Conf |
|----------|----------|----------|----------|----------|-------------------------|------------------|--|--|----------|
| 0.19087  | 0.151628 | 0.206287 | 0.1399   | 0.175061 |                         |                  |  |  |          |
| 0.192689 | 0.151295 | 0.18284  | 0.127605 | 0.153288 |                         |                  |  |  |          |
| 0.196812 | 0.177503 | 0.172196 | 0.136336 | 0.150953 | RUN-IN                  | 0.163804         | 0.02143                                    |  |          |
| 0.184186 | 0.173589 | 0.166817 | 0.141647 | 0.144553 |                         |                  |  |  |          |
| 0.178176 | 0.159495 | 0.158    | 0.142196 | 0.141415 | XXXXXXXXXXXXXXXXXXXXXXX |                  |  |  |          |
| 0.108597 | 0.098847 | 0.120341 | 0.098847 | 0.100764 |                         |                  |  |  |          |
| 0.101912 | 0.105867 | 0.10389  | 0.092022 | 0.084107 |                         |                  |  |  |          |
| 0.109735 | 0.112397 | 0.112397 | 0.101749 | 0.098423 | DESIGN                  | 0.107545         | 0.010072                                   | 11.87854                                       | 4.527052 |
| 0.111972 | 0.114669 | 0.110827 | 0.108608 | 0.103553 |                         |                  |  | YES  | YES      |
| 0.130482 | 0.115636 | 0.115636 | 0.114854 | 0.110945 | XXXXXXXXXXXXXXXXXXXXXXX |                  |  |  |          |
| 0.167252 | 0.151626 | 0.151626 | 0.092929 | 0.096847 |                         |                  |  |  |          |
| 0.13353  | 0.135504 | 0.13353  | 0.088065 | 0.095979 | USED STUD RUN-IN        |                  |  |  |          |
| 0.138995 | 0.142982 | 0.137666 | 0.100417 | 0.107074 | 0.126673                | 0.022385         |  |  |          |
| 0.140678 | 0.147458 | 0.142615 | 0.102542 | 0.112646 |                         |                  |  |  |          |
| 0.146034 | 0.139073 | 0.139854 | 0.107036 | 0.114854 | XXXXXXXXXXXXXXXXXXXXXXX |                  |  |  |          |
| 0.147718 | 0.112512 | 0.132078 | 0.08509  | 0.08117  |                         |                  |  |  |          |
| 0.131555 | 0.094    | 0.109821 | 0.105867 | 0.082128 | USED STUD DESIGN        |                  |  |  |          |
| 0.135007 | 0.105742 | 0.113728 | 0.096423 | 0.089763 | 0.110464                | 0.018756         | 0.685551                                   | 3.46767  |          |
| 0.138741 | 0.111638 | 0.115679 | 0.098498 | 0.096476 |                         |                  | NO   | YES  |          |
| 0.141415 | 0.114072 | 0.115636 | 0.106254 | 0.100583 | XXXXXXXXXXXXXXXXXXXXXXX |                  |  |  |          |
|          |          |          |          |          | OVERALL                 |                  |  |  |          |
| MEAN     | 0.146695 | 0.130677 | 0.14362  | 0.109244 | 0.127121                | 0.029144         |  |  |          |
| STD DEV  | 0.028947 | 0.025346 | 0.028528 | 0.018369 | 0.026724                |                  |  |  |          |

TABLE 9: ALLOY I, LUBRICANT NO. 9

| STUD1    | STUD2    | STUD3    | STUD4    | STUD5    | MEAN<br>VALUE    | STD<br>DEVIATION | TEST<br>FOR         |   | TEST<br>FOR |
|----------|----------|----------|----------|----------|------------------|------------------|---------------------|---|-------------|
|          |          |          |          |          |                  |                  | MEAN                | VARIANCE                                    |             |
| 0.167252 | 0.19847  | 0.178984 | 0.326764 | 0.217958 |                  |                  | t-TEST<br>t* = 1.68 | F-TEST<br>F* = 1.98                         | 95% Confl   |
| 0.149321 | 0.192689 | 0.18284  | 0.265428 | 0.230072 |                  |                  |                     |   |             |
| 0.156266 | 0.201901 | 0.203173 | 0.26827  | 0.25368  | RUN-IN           | 0.222099         | 0.05263             |   |             |
| 0.154236 | 0.197152 | 0.220288 | 0.283953 | 0.263875 |                  |                  |                     |   |             |
| 0.152788 | 0.212573 | 0.255717 | 0.319916 | 0.288956 | XXXXXXX          | XXXXXXX          | XXXXXXX             | XXXXXXX                                     | XXXXXXX     |
| 0.092929 | 0.19847  | 0.171157 | 0.178984 | 0.147718 |                  |                  |                     |   |             |
| 0.095979 | 0.200564 | 0.161158 | 0.171016 | 0.141427 |                  |                  |                     |   |             |
| 0.104411 | 0.194266 | 0.177503 | 0.181483 | 0.150953 | DESIGN           | 0.166164         | 0.036231            | DESIGN VS RUN-IN<br>t<br>4.377079           | 2.110071    |
| 0.114669 | 0.215663 | 0.197152 | 0.174556 | 0.172622 |                  |                  |                     |   |             |
| 0.12892  | 0.223853 | 0.203817 | 0.172947 | 0.181911 | XXXXXXX          | XXXXXXX          | XXXXXXX             | XXXXXXX                                     | XXXXXXX     |
| 0.19067  | 0.182867 | 0.167252 | 0.163347 | 0.147718 |                  |                  |                     |   |             |
| 0.18087  | 0.18678  | 0.174958 | 0.15524  | 0.147348 | USED STUD RUN-IN |                  |                     |   |             |
| 0.191721 | 0.198084 | 0.214619 | 0.162905 | 0.177503 |                  | 0.190711         | 0.029152            |   |             |
| 0.211036 | 0.213812 | 0.237673 | 0.168752 | 0.204558 |                  |                  |                     |   |             |
| 0.24018  | 0.212573 | 0.252611 | 0.164727 | 0.219964 | XXXXXXX          | XXXXXXX          | XXXXXXX             | XXXXXXX                                     | XXXXXXX     |
| 0.155534 | 0.128166 | 0.128166 | 0.167252 | 0.108597 |                  |                  |                     |   |             |
| 0.147348 | 0.12563  | 0.127605 | 0.141427 | 0.101912 | USED STUD DESIGN |                  |                     |   |             |
| 0.158922 | 0.132348 | 0.136336 | 0.140324 | 0.107074 |                  | 0.137453         | 0.020245            | DESIGN VS USED STUD DESIGN<br>t<br>-3.45891 | 3.202715    |
| 0.170687 | 0.141647 | 0.140678 | 0.141647 | 0.109617 |                  |                  |                     | YES   | YES         |
| 0.178176 | 0.142977 | 0.155009 | 0.137511 | 0.111727 | XXXXXXX          | XXXXXXX          | XXXXXXX             | XXXXXXX                                     | XXXXXXX     |
|          |          |          |          |          | OVERALL          |                  |                     |   |             |
| MEAN     | 0.157095 | 0.185024 | 0.199925 | 0.17426  |                  | 0.179107         | 0.047711            |   |             |
| STD DEV  | 0.03759  | 0.031901 | 0.030744 | 0.061986 |                  |                  |                     |   |             |

TABLE 10: ALLOY TYPE I, LUBRICANT NO.10

| STUD1    | STUD2    | STUD3    | STUD4    | STUD5    | MEAN<br>VALUE           | STD<br>DEVIATION | TEST<br>FOR<br>MEAN<br>t-TEST<br>t*=1.68 | TEST<br>FOR<br>VARIANCE<br>F-TEST<br>F*=1.98 | 95% Confl |
|----------|----------|----------|----------|----------|-------------------------|------------------|--|--|-----------|
| 0.217958 | 0.188768 | 0.217958 | 0.128168 | 0.1399   |                         |                  |  |  |           |
| 0.18087  | 0.171016 | 0.204501 | 0.137479 | 0.13353  |                         |                  |  |  |           |
| 0.164232 | 0.170869 | 0.189175 | 0.158266 | 0.132348 | RUN-IN                  | 0.164031         | 0.025156                                 |  |           |
| 0.154236 | 0.172622 | 0.166817 | 0.159076 | 0.139709 |                         |                  |  |  |           |
| 0.144538 | 0.165475 | 0.152018 | 0.168464 | 0.146782 | XXXXXXXXXXXXXXXXXXXXXXX |                  |  |  |           |
| 0.100764 | 0.120341 | 0.100764 | 0.120341 | 0.092929 |                         |                  |  |  |           |
| 0.094    | 0.111798 | 0.101912 | 0.109821 | 0.095979 |                         |                  |  |  |           |
| 0.093759 | 0.131019 | 0.109735 | 0.116389 | 0.107074 | DESIGN                  | 0.113401         | 0.013923                                 | 8.804803                                     | 3.264683  |
| 0.101531 | 0.139709 | 0.128808 | 0.12174  | 0.114669 |                         |                  |  | YES  | YES       |
| 0.109381 | 0.139073 | 0.129701 | 0.123451 | 0.120325 | XXXXXXXXXXXXXXXXXXXXXXX |                  |  |  |           |
| 0.116427 | 0.120341 | 0.128166 | 0.120341 | 0.128166 |                         |                  |  |  |           |
| 0.115751 | 0.109821 | 0.123654 | 0.12958  | 0.127605 | USED STUD RUN-IN        |                  |  |  |           |
| 0.12304  | 0.117719 | 0.137666 | 0.133878 | 0.132348 |                         | 0.126361         | 0.008017                                 |  |           |
| 0.12073  | 0.124769 | 0.131837 | 0.136803 | 0.140678 |                         |                  |  |  |           |
| 0.117199 | 0.125795 | 0.127358 | 0.129701 | 0.139854 | XXXXXXXXXXXXXXXXXXXXXXX |                  |  |  |           |
| 0.100764 | 0.08901  | 0.104681 | 0.092929 | 0.108597 |                         |                  |  |  |           |
| 0.101912 | 0.088065 | 0.101912 | 0.094    | 0.095979 | USED STUD DESIGN        |                  |  |  |           |
| 0.104411 | 0.093759 | 0.108405 | 0.105742 | 0.108405 |                         | 0.104191         | 0.009164                                 | 2.762597                                     | 2.308292  |
| 0.103553 | 0.098498 | 0.115679 | 0.107598 | 0.114869 |                         |                  |  | YES  | YES       |
| 0.099769 | 0.113291 | 0.124232 | 0.110163 | 0.118762 | XXXXXXXXXXXXXXXXXXXXXXX |                  |  |  |           |
| MEAN     | 0.123241 | 0.129488 | 0.143338 | 0.125086 | OVERALL                 | 0.126998         | 0.027583                                 |  |           |
| STD DEV  | 0.032299 | 0.029883 | 0.035985 | 0.020125 |                         | R=0.1289         |  |  |           |

## **ATTACHMENT II**

### **Phase I - Coefficient of Friction Dataset**

#### **Monel K-500 (K-Monel)/Monel 400**

The main body of the following tables list each individual calculated coefficient of friction value, based on the equation of Appendix A, for every Monel K-500 stud tested. The mean coefficient of friction and standard deviations for each individual stud is provided at the bottom of the table, while the mean coefficient of friction, standard deviation and the results of the statistical tests performed for all studs tested under the same loading sequence are provided to the right of the individual values.

TABLE 1: ALLOY M, LUBRICANT NO. 1

| STUD1    | STUD2    | STUD3    | STUD4    | STUD5    | MEAN<br>VALUE        | STD<br>DEVIATION | TEST<br>FOR<br>MEAN<br>t-TEST<br>t* = 1.68 | TEST<br>FOR<br>VARIANCE<br>F-TEST<br>F* = 1.98 | 95% Confl |
|----------|----------|----------|----------|----------|----------------------|------------------|--|--|-----------|
| 0.108455 | 0.097655 | 0.094721 | 0.121113 | 0.097655 |                      |                  |  |  |           |
| 0.113046 | 0.096638 | 0.102608 | 0.130931 | 0.09813  |                      |                  |  |  |           |
| 0.125574 | 0.115489 | 0.108426 | 0.138517 | 0.111453 | RUN-IN               | 0.114448         | 0.012856                                   |  |           |
| 0.117683 | 0.118416 | 0.106684 | 0.138748 | 0.114017 |                      |                  |  |  |           |
| 0.11954  | 0.126285 | 0.108293 | 0.131343 | 0.121789 | XXXXXXXXXXXXXXXXXXXX |                  |  |  |           |
| 0.088852 | 0.100589 | 0.082981 | 0.082981 | 0.091787 |                      |                  |  |  |           |
| 0.089176 | 0.102606 | 0.08619  | 0.087683 | 0.095146 |                      |                  |  |  |           |
| 0.098332 | 0.107417 | 0.092274 | 0.099342 | 0.10338  | DESIGN               | 0.099245         | 0.010327                                   | DESIGN VS RUN-IN<br>t<br>F                     | 1.57393   |
| 0.100082 | 0.110351 | 0.092531 | 0.103017 | 0.108864 |                      |                  |  | YES  | NO        |
| 0.108855 | 0.117853 | 0.098483 | 0.113917 | 0.118415 | XXXXXXXXXXXXXXXXXXXX |                  |  |  |           |
| 0.088852 | 0.091787 | 0.088852 | 0.100589 | 0.091787 |                      |                  |  |  |           |
| 0.095146 | 0.09813  | 0.087683 | 0.095146 | 0.093653 | USED STUD RUN-IN     |                  |  |  |           |
| 0.10237  | 0.108426 | 0.101361 | 0.098332 | 0.101361 |                      | 0.100329         | 0.007528                                   |  |           |
| 0.10375  | 0.109618 | 0.105217 | 0.098615 | 0.102283 |                      |                  |  |  |           |
| 0.109418 | 0.115604 | 0.109418 | 0.101419 | 0.109418 | XXXXXXXXXXXXXXXXXXXX |                  |  |  |           |
| 0.085917 | 0.088852 | 0.071235 | 0.088852 | 0.085917 |                      |                  |  |  |           |
| 0.090688 | 0.095146 | 0.081711 | 0.08619  | 0.083204 | USED STUD DESIGN     |                  |  | DESIGN VS USED STUD DESIGN<br>t<br>F           | 1.101752  |
| 0.10237  | 0.106408 | 0.100352 | 0.087224 | 0.097323 |                      | 0.095353         | 0.01084                                    | -1.29875                                       | NO        |
| 0.104484 | 0.105951 | 0.103017 | 0.087179 | 0.099349 |                      |                  |  | NO   | NO        |
| 0.110543 | 0.113355 | 0.111105 | 0.091435 | 0.106043 | XXXXXXXXXXXXXXXXXXXX |                  |  |  |           |
|          |          |          |          |          | OVERALL              |                  |  |  |           |
| MEAN     | 0.103056 | 0.106329 | 0.097715 | 0.104129 |                      | 0.102344         | 0.01271                                    |  |           |
| STD DEV  | 0.01118  | 0.009879 | 0.008985 | 0.018382 |                      |                  |  |  |           |

TABLE 2: ALLOY M, LUBRICANT NO. 2

| STUD1    | STUD2    | STUD3    | STUD4    | STUD5    | MEAN<br>VALUE           | STD<br>DEVIATION | TEST<br>FOR<br>MEAN | TEST<br>FOR<br>VARIANCE | TEST<br>F-TEST<br>F*=1.98 | 95% Confl |
|----------|----------|----------|----------|----------|-------------------------|------------------|---------------------|-------------------------|---------------------------|-----------|
| 0.106455 | 0.100599 | 0.098852 | 0.091787 | 0.106455 |                         |                  |                     |                         |                           |           |
| 0.110084 | 0.110064 | 0.095146 | 0.095146 | 0.110064 |                         |                  |                     |                         |                           |           |
| 0.118515 | 0.115489 | 0.10237  | 0.10237  | 0.113471 | RUN-IN                  | 0.107763         | 0.008789            |                         |                           |           |
| 0.115483 | 0.11475  | 0.10155  | 0.105217 | 0.113284 |                         |                  |                     |                         |                           |           |
| 0.120102 | 0.116168 | 0.107168 | 0.115042 | 0.118978 | XXXXXXXXXXXXXXXXXXXXXXX |                  |                     |                         |                           |           |
| 0.103522 | 0.098852 | 0.077109 | 0.098852 | 0.100589 |                         |                  |                     |                         |                           |           |
| 0.099622 | 0.095146 | 0.083204 | 0.096638 | 0.095146 |                         |                  |                     |                         |                           |           |
| 0.106408 | 0.10237  | 0.095304 | 0.107417 | 0.109435 | DESIGN                  | 0.100858         | 0.009339            | 2.699949                | 1.128956                  |           |
| 0.105951 | 0.105217 | 0.096353 | 0.108151 | 0.110351 |                         |                  |                     | YES                     | NO                        |           |
| 0.108855 | 0.111105 | 0.100832 | 0.110543 | 0.114479 | XXXXXXXXXXXXXXXXXXXXXXX |                  |                     |                         |                           |           |
| 0.091787 | 0.103522 | 0.094721 | 0.097655 | 0.094721 |                         |                  |                     |                         |                           |           |
| 0.08619  | 0.107081 | 0.105589 | 0.096638 | 0.101114 | USED STUD RUN-IN        |                  |                     |                         |                           |           |
| 0.093284 | 0.116497 | 0.110444 | 0.098332 | 0.106408 |                         | 0.103424         | 0.009775            |                         |                           |           |
| 0.091766 | 0.120615 | 0.110351 | 0.100082 | 0.105217 |                         |                  |                     |                         |                           |           |
| 0.098483 | 0.127971 | 0.111105 | 0.104355 | 0.111667 | XXXXXXXXXXXXXXXXXXXXXXX |                  |                     |                         |                           |           |
| 0.082981 | 0.094721 | 0.077109 | 0.088852 | 0.094721 |                         |                  |                     |                         |                           |           |
| 0.081711 | 0.104098 | 0.084697 | 0.092161 | 0.095146 | USED STUD DESIGN        |                  |                     |                         |                           |           |
| 0.088234 | 0.117506 | 0.096313 | 0.100352 | 0.10338  |                         | 0.097596         | 0.012015            | -1.07192                | 1.655253                  |           |
| 0.086414 | 0.119882 | 0.097117 | 0.098615 | 0.103017 |                         |                  |                     | NO                      | NO                        |           |
| 0.090848 | 0.125723 | 0.100832 | 0.10548  | 0.10998  | XXXXXXXXXXXXXXXXXXXXXXX |                  |                     |                         |                           |           |
|          |          |          |          |          | OVERALL                 |                  |                     |                         |                           |           |
| MEAN     | 0.099334 | 0.109868 | 0.098673 | 0.100184 | 0.102415                | 0.010585         |                     |                         |                           |           |
| STD DEV  | 0.011904 | 0.01058  | 0.010077 | 0.00716  | 0.00727                 |                  |                     |                         |                           |           |

TABLE 3: ALLOY M, LUBRICANT NO. 3

| STUD1    | STUD2    | STUD3    | STUD4    | STUD5    | MEAN<br>VALUE                | STD<br>DEVIATION | TEST<br>FOR<br>MEAN        | TEST<br>FOR<br>VARIANCE |
|----------|----------|----------|----------|----------|------------------------------|------------------|----------------------------|-------------------------|
| 0.065359 | 0.062421 | 0.062421 | 0.059482 | 0.065359 |                              |                  | t-TEST<br>t* = 1.68        | F-TEST<br>F* = 1.98     |
| 0.07275  | 0.059301 | 0.06229  | 0.063785 | 0.068268 |                              |                  |                            | 95% Conf                |
| 0.082173 | 0.061957 | 0.071057 | 0.074089 | 0.074089 | RUN-IN                       | 0.073697         | 0.011796                   |                         |
| 0.086414 | 0.064226 | 0.083355 | 0.078766 | 0.079531 |                              |                  |                            |                         |
| 0.100832 | 0.073145 | 0.096134 | 0.091435 | 0.083798 | XXXXXXXXXXXXXXXXXXXXXXXXXXXX |                  |                            |                         |
| 0.059482 | 0.053603 | 0.062421 | 0.056543 | 0.053603 |                              |                  | DESIGN VS RUN-IN           |                         |
| 0.063785 | 0.054816 | 0.065279 | 0.059301 | 0.059301 |                              |                  | t                          | F                       |
| 0.066002 | 0.059934 | 0.071057 | 0.059934 | 0.069035 | DESIGN                       | 0.064796         | 0.008257                   | 3.091006 2.041021       |
| 0.06193  | 0.062695 | 0.07188  | 0.059633 | 0.07494  |                              |                  | YES                        | YES                     |
| 0.066407 | 0.070695 | 0.085561 | 0.068857 | 0.08321  | XXXXXXXXXXXXXXXXXXXXXXXXXXXX |                  |                            |                         |
| 0.056543 | 0.056543 | 0.068297 | 0.059482 | 0.065359 |                              |                  |                            |                         |
| 0.060796 | 0.060796 | 0.063785 | 0.057806 | 0.06229  | USED STUD RUN-IN             |                  |                            |                         |
| 0.064991 | 0.066002 | 0.068024 | 0.057912 | 0.066002 | 0.064968                     | 0.006282         |                            |                         |
| 0.064992 | 0.064992 | 0.071115 | 0.057336 | 0.065757 |                              |                  |                            |                         |
| 0.079096 | 0.071307 | 0.079096 | 0.062731 | 0.073145 | XXXXXXXXXXXXXXXXXXXXXXXXXXXX |                  |                            |                         |
| 0.050663 | 0.047723 | 0.050663 | 0.056543 | 0.056543 |                              |                  | DESIGN VS USED STUD DESIGN |                         |
| 0.057806 | 0.050331 | 0.053321 | 0.051826 | 0.057806 | USED STUD DESIGN             |                  | t                          | F                       |
| 0.068002 | 0.055889 | 0.057912 | 0.05083  | 0.055889 | 0.057177                     | 0.006389         | -3.64925                   | 1.670316                |
| 0.064226 | 0.057336 | 0.06193  | 0.051975 | 0.051975 |                              |                  | YES                        | NO                      |
| 0.071307 | 0.063957 | 0.071307 | 0.054765 | 0.060893 | XXXXXXXXXXXXXXXXXXXXXXXXXXXX |                  |                            |                         |
|          |          |          |          |          | OVERALL                      |                  |                            |                         |
| MEAN     | 0.068078 | 0.060883 | 0.072118 | 0.061652 | 0.065159                     | 0.010211         |                            |                         |
| STD DEV  | 0.011156 | 0.006727 | 0.009885 | 0.009917 | 0.009457                     |                  |                            |                         |

TABLE 4: ALLOY M, LUBRICANT NO. 4

|         | TEST FOR MEAN |          |          |          | TEST FOR VARIANCE |                      |               |                     |
|---------|---------------|----------|----------|----------|-------------------|----------------------|---------------|---------------------|
|         | STUD1         | STUD2    | STUD3    | STUD4    | STUD5             | MEAN VALUE           | STD DEVIATION | F-TEST<br>F* = 1.98 |
|         | 0.1504        | 0.144545 | 0.1504   | 0.1504   | 0.156252          |                      |               |                     |
|         | 0.139869      | 0.147314 | 0.144336 | 0.141358 | 0.154758          |                      |               |                     |
|         | 0.143354      | 0.150123 | 0.152057 | 0.147222 | 0.15979           | RUN-IN               | 0.150475      | 0.009905            |
|         | 0.136642      | 0.145765 | 0.144362 | 0.140853 | 0.157689          |                      |               |                     |
|         | 0.137963      | 0.171055 | 0.154442 | 0.164031 | 0.178907          | XXXXXXXXXXXXXXXXXXXX |               |                     |
|         | 0.132832      | 0.141618 | 0.159178 | 0.162103 | 0.1738            |                      |               |                     |
|         | 0.124971      | 0.133911 | 0.145825 | 0.153268 | 0.154756          |                      |               |                     |
|         | 0.13755       | 0.148189 | 0.153023 | 0.15689  | 0.162889          | DESIGN               | 0.152599      | 0.014072            |
|         | 0.137344      | 0.145063 | 0.156987 | 0.156286 | 0.156987          |                      |               |                     |
|         | 0.137863      | 0.158285 | 0.177492 | 0.175737 | 0.172226          | XXXXXXXXXXXXXXXXXXXX |               |                     |
|         | 0.1504        | 0.158252 | 0.162103 | 0.153328 | 0.182569          |                      |               |                     |
|         | 0.141358      | 0.153268 | 0.160708 | 0.168145 | 0.168145          | USED STUD RUN-IN     |               |                     |
|         | 0.152057      | 0.161722 | 0.168554 | 0.177179 | 0.171384          | 0.16323              | 0.011214      |                     |
|         | 0.145063      | 0.155585 | 0.161896 | 0.170292 | 0.166102          |                      |               |                     |
|         | 0.163445      | 0.172811 | 0.158638 | 0.178662 | 0.185097          | XXXXXXXXXXXXXXXXXXXX |               |                     |
|         | 0.153326      | 0.165028 | 0.1738   | 0.194255 | 0.176724          |                      |               |                     |
|         | 0.154756      | 0.165171 | 0.169633 | 0.185985 | 0.177067          | USED STUD DESIGN     | 0.176333      | 0.013195            |
|         | 0.161722      | 0.177179 | 0.17235  | 0.178144 | 0.190372          |                      |               |                     |
|         | 0.156987      | 0.168204 | 0.168905 | 0.173719 | 0.183998          |                      |               |                     |
|         | 0.183342      | 0.190384 | 0.188606 | 0.202319 | 0.196353          | XXXXXXXXXXXXXXXXXXXX |               |                     |
|         |               |          |          |          |                   | OVERALL              |               |                     |
| MEAN    | 0.147067      | 0.157574 | 0.1564   | 0.168509 | 0.171183          |                      | 0.160659      | 0.015836            |
| STD DEV | 0.01317       | 0.013902 | 0.008903 | 0.016978 | 0.012521          |                      |               |                     |

DESIGN VS RUN-IN  
t F  
-0.61705 2.018427  
NO YES

DESIGN VS USED STUD DESIGN  
t F  
6.151762 1.137418  
YES NO

TABLE 5: ALLOY M, LUBRICANT NO. 5

| STUD1    | STUD2    | STUD3    | STUD4    | STUD5    | MEAN<br>VALUE           | STD<br>DEVIATION | TEST<br>FOR<br>MEAN<br>t-TEST<br>t*=-1.68 | TEST<br>FOR<br>VARIANCE<br>F-TEST<br>F*=-1.98 | 95% Confi |
|----------|----------|----------|----------|----------|-------------------------|------------------|---|---|-----------|
| 0.085917 | 0.085917 | 0.091787 | 0.118182 | 0.100589 |                         |                  |   |   |           |
| 0.093653 | 0.092161 | 0.093853 | 0.114537 | 0.085146 |                         |                  |   |   |           |
| 0.105398 | 0.101361 | 0.101361 | 0.118515 | 0.098332 | RUN-IN                  | 0.102836         | 0.010448                                  |   |           |
| 0.105951 | 0.096353 | 0.102283 | 0.11695  | 0.099349 |                         |                  |   |   |           |
| 0.113917 | 0.101419 | 0.106805 | 0.125723 | 0.100832 | XXXXXXXXXXXXXXXXXXXXXXX |                  |   |   |           |
| 0.085917 | 0.077109 | 0.071235 | 0.100589 | 0.074172 |                         |                  |   |   |           |
| 0.087683 | 0.078724 | 0.078724 | 0.093853 | 0.077231 |                         |                  |   |   |           |
| 0.099342 | 0.082173 | 0.084194 | 0.099342 | 0.085204 | DESIGN                  | 0.08758          | 0.009691                                  | DESIGN VS RUN-IN<br>t<br>5.282535             | 1.162519  |
| 0.097881 | 0.081825 | 0.081825 | 0.099349 | 0.083355 |                         |                  |   | YES   | NO        |
| 0.100832 | 0.088498 | 0.084385 | 0.107168 | 0.089086 | XXXXXXXXXXXXXXXXXXXXXXX |                  |   |   |           |
| 0.080045 | 0.080045 | 0.071235 | 0.109387 | 0.080045 |                         |                  |   |   |           |
| 0.078724 | 0.084697 | 0.066774 | 0.102806 | 0.080218 | USED STUD RUN-IN        |                  |   |   |           |
| 0.084194 | 0.086214 | 0.068024 | 0.107417 | 0.086214 | 0.085517                | 0.013619         |   |   |           |
| 0.084884 | 0.083355 | 0.067288 | 0.108884 | 0.081825 |                         |                  |   |   |           |
| 0.089086 | 0.089086 | 0.067632 | 0.114479 | 0.085561 | XXXXXXXXXXXXXXXXXXXXXXX |                  |   |   |           |
| 0.082981 | 0.080045 | 0.074172 | 0.097655 | 0.080045 |                         |                  |   |   |           |
| 0.078724 | 0.077231 | 0.07275  | 0.093853 | 0.077231 | USED STUD DESIGN        |                  |   |   |           |
| 0.089244 | 0.082173 | 0.077121 | 0.092274 | 0.082173 | 0.083096                | 0.006668         |   | DESIGN VS USED STUD DESIGN<br>t<br>-1.90598   | 2.11934   |
| 0.088708 | 0.08412  | 0.074175 | 0.086414 | 0.08106  |                         |                  |   | YES   | YES       |
| 0.090848 | 0.088498 | 0.076745 | 0.088498 | 0.080859 | XXXXXXXXXXXXXXXXXXXXXXX |                  |   |   |           |
|          |          |          |          |          | OVERALL                 |                  |   |   |           |
| MEAN     | 0.091196 | 0.08605  | 0.092467 | 0.104764 | 0.089707                | 0.012798         |   |   |           |
| STD DEV  | 0.009787 | 0.00718  | 0.013947 | 0.011082 |                         |                  |   |   |           |

TABLE 6: ALLOY M, LUBRICANT NO.6

| STUD1    | STUD2    | STUD3    | STUD4    | STUD5    | MEAN<br>VALUE        | STD<br>DEVIATION | TEST<br>FOR       |                   | TEST<br>FOR<br>VARIANCE |
|----------|----------|----------|----------|----------|----------------------|------------------|-------------------|-------------------|-------------------------|
|          |          |          |          |          |                      |                  | t-TEST<br>t*=1.68 | F-TEST<br>F*=1.98 |                         |
| 0.077109 | 0.091787 | 0.077109 | 0.085917 | 0.094721 |                      |                  |                   |                   |                         |
| 0.075737 | 0.093853 | 0.08619  | 0.105589 | 0.09813  |                      |                  |                   |                   |                         |
| 0.079142 | 0.10237  | 0.093284 | 0.121541 | 0.105398 | RUN-IN               | 0.097201         | 0.014951          |                   |                         |
| 0.08259  | 0.100082 | 0.094059 | 0.125745 | 0.106684 |                      |                  |                   |                   |                         |
| 0.086148 | 0.104355 | 0.100245 | 0.131905 | 0.110543 | XXXXXXXXXXXXXXXXXXXX |                  |                   |                   |                         |
| 0.065359 | 0.091787 | 0.085917 | 0.100589 | 0.098852 |                      |                  |                   |                   |                         |
| 0.06229  | 0.084897 | 0.083204 | 0.098622 | 0.075737 |                      |                  |                   |                   |                         |
| 0.060946 | 0.088234 | 0.087224 | 0.10338  | 0.079142 | DESIGN               | 0.084523         | 0.014977          | 2.995584          | 1.003423                |
| 0.058102 | 0.084884 | 0.086414 | 0.108151 | 0.079531 |                      |                  |                   |                   |                         |
| 0.059667 | 0.089673 | 0.089673 | 0.115604 | 0.084385 | XXXXXXXXXXXXXXXXXXXX |                  |                   |                   |                         |
| 0.068297 | 0.100569 | 0.085917 | 0.097855 | 0.082981 |                      |                  |                   |                   |                         |
| 0.065279 | 0.095146 | 0.080218 | 0.09813  | 0.077231 | USED STUD RUN-IN     |                  |                   |                   |                         |
| 0.068024 | 0.092274 | 0.089244 | 0.098332 | 0.082173 |                      | 0.086762         | 0.011624          |                   |                         |
| 0.068819 | 0.090237 | 0.093295 | 0.096353 | 0.078766 |                      |                  |                   |                   |                         |
| 0.076745 | 0.091435 | 0.104355 | 0.103181 | 0.084385 | XXXXXXXXXXXXXXXXXXXX |                  |                   |                   |                         |
| 0.074172 | 0.080045 | 0.077109 | 0.085917 | 0.085917 |                      |                  |                   |                   |                         |
| 0.063785 | 0.080218 | 0.07275  | 0.081711 | 0.077231 | USED STUD DESIGN     |                  |                   |                   |                         |
| 0.062968 | 0.078131 | 0.0751   | 0.092274 | 0.073078 |                      | 0.077353         | 0.009314          | -2.03246          | 2.585455                |
| 0.061164 | 0.072645 | 0.078001 | 0.091766 | 0.069584 |                      |                  |                   | YES               | YES                     |
| 0.063957 | 0.077921 | 0.087911 | 0.096722 | 0.073757 | XXXXXXXXXXXXXXXXXXXX |                  |                   |                   |                         |
|          |          |          |          |          | OVERALL              |                  |                   |                   |                         |
| MEAN     | 0.069015 | 0.089508 | 0.08909  | 0.102004 | 0.085411             | 0.08646          | 0.014608          |                   |                         |
| STD DEV  | 0.008189 | 0.008771 | 0.007141 | 0.013223 | 0.011802             |                  |                   |                   |                         |

TABLE 7-ALLOY M, LUBRICANT NO. 7

| STUD1    | STUD2    | STUD3    | STUD4    | STUD5    | MEAN<br>VALUE           | STD<br>DEVIATION | TEST<br>FOR<br>MEAN        | TEST<br>FOR<br>VARIANCE |
|----------|----------|----------|----------|----------|-------------------------|------------------|----------------------------|-------------------------|
| 0.153326 | 0.135761 | 0.147473 | 0.147473 | 0.153326 |                         |                  | t-TEST<br>t*=-1.68         | F-TEST<br>F*=-1.98      |
| 0.150291 | 0.144336 | 0.154756 | 0.138379 | 0.145825 |                         |                  |                            | 95% Conf                |
| 0.163655 | 0.15689  | 0.16752  | 0.147222 | 0.15109  | RUN-IN                  | 0.153698         | 0.0109                     |                         |
| 0.161896 | 0.161194 | 0.147168 | 0.147168 | 0.150675 |                         |                  |                            |                         |
| 0.163342 | 0.177492 | 0.156636 | 0.148401 | 0.151147 | XXXXXXXXXXXXXXXXXXXXXXX |                  |                            |                         |
| 0.170877 | 0.159178 | 0.162103 | 0.159178 | 0.1504   |                         |                  | DESIGN VS RUN-IN           |                         |
| 0.154756 | 0.15922  | 0.157732 | 0.147314 | 0.150291 |                         |                  | t                          | F                       |
| 0.165588 | 0.168486 | 0.160756 | 0.153023 | 0.15109  | DESIGN                  | 0.159773         | 0.008808                   | -2.16742 1.531555       |
| 0.159091 | 0.170292 | 0.155585 | 0.155585 | 0.147168 |                         |                  | YES                        | YES                     |
| 0.172811 | 0.177492 | 0.176322 | 0.158834 | 0.151147 | XXXXXXXXXXXXXXXXXXXXXXX |                  |                            |                         |
| 0.1738   | 0.167853 | 0.162103 | 0.1504   | 0.156252 |                         |                  |                            |                         |
| 0.153268 | 0.157732 | 0.157732 | 0.148802 | 0.154756 | USED STUD RUN-IN        |                  |                            |                         |
| 0.155923 | 0.165588 | 0.160756 | 0.154957 | 0.158823 |                         | 0.156882         | 0.006711                   |                         |
| 0.154182 | 0.163999 | 0.15278  | 0.147168 | 0.151377 |                         |                  |                            |                         |
| 0.154442 | 0.166373 | 0.1495   | 0.14895  | 0.154442 | XXXXXXXXXXXXXXXXXXXXXXX |                  |                            |                         |
| 0.159178 | 0.165028 | 0.156252 | 0.147473 | 0.1504   |                         |                  | DESIGN VS USED STUD DESIGN |                         |
| 0.148802 | 0.157732 | 0.150291 | 0.150291 | 0.145925 | USED STUD DESIGN        |                  | t                          | F                       |
| 0.15399  | 0.15979  | 0.150123 | 0.153023 | 0.154957 |                         | 0.153145         | 0.005955                   | -3.11687 2.187584       |
| 0.150675 | 0.159792 | 0.145765 | 0.145765 | 0.151377 |                         |                  | YES                        | YES                     |
| 0.168958 | 0.159383 | 0.14895  | 0.147303 | 0.1495   | XXXXXXXXXXXXXXXXXXXXXXX |                  |                            |                         |
|          |          |          |          |          | OVERALL                 |                  |                            |                         |
| MEAN     | 0.160343 | 0.161685 | 0.157928 | 0.149835 | 0.151493                | 0.155874         | 0.00862                    |                         |
| STD DEV  | 0.009333 | 0.009639 | 0.007658 | 0.00484  | 0.00327                 |                  |                            |                         |

TABLE 8: ALLOY M, LUBRICANT NO. 8

| STUD1    | STUD2    | STUD3    | STUD4    | STUD5    | MEAN<br>VALUE           | STD<br>DEVIATION | TEST<br>FOR |          | TEST<br>FOR<br>VARIANCE |
|----------|----------|----------|----------|----------|-------------------------|------------------|-------------|----------|-------------------------|
|          |          |          |          |          |                         |                  | t-TEST      | F-TEST   |                         |
| 0.094721 | 0.094721 | 0.091787 | 0.106455 | 0.088852 |                         |                  | t*=1.88     | F*=1.98  | 95% Confl               |
| 0.099622 | 0.095146 | 0.092161 | 0.104098 | 0.092161 |                         |                  |             |          |                         |
| 0.106408 | 0.104389 | 0.098332 | 0.110444 | 0.097323 | RUN-IN                  | 0.102214         | 0.00768     |          |                         |
| 0.108151 | 0.106684 | 0.100816 | 0.108151 | 0.100082 |                         |                  |             |          |                         |
| 0.114479 | 0.114479 | 0.11223  | 0.11223  | 0.101419 | XXXXXXXXXXXXXXXXXXXXXXX |                  |             |          |                         |
| 0.088852 | 0.091787 | 0.085917 | 0.085917 | 0.077109 |                         |                  |             |          |                         |
| 0.089176 | 0.093653 | 0.092161 | 0.092161 | 0.093204 |                         |                  |             |          |                         |
| 0.095304 | 0.10237  | 0.101361 | 0.096313 | 0.090254 | DESIGN                  | 0.094276         | 0.008149    | 3.548844 | 1.131799                |
| 0.092531 | 0.105951 | 0.105217 | 0.092531 | 0.087943 |                         |                  | YES         | NO       |                         |
| 0.097309 | 0.111667 | 0.108293 | 0.097896 | 0.092023 | XXXXXXXXXXXXXXXXXXXXXXX |                  |             |          |                         |
| 0.091787 | 0.091787 | 0.088852 | 0.091787 | 0.080045 |                         |                  |             |          |                         |
| 0.089176 | 0.087683 | 0.093653 | 0.093653 | 0.087683 | USED STUD RUN-IN        | 0.097466         | 0.008699    |          |                         |
| 0.096313 | 0.104389 | 0.107417 | 0.096313 | 0.097323 |                         |                  |             |          |                         |
| 0.096353 | 0.105951 | 0.111084 | 0.097117 | 0.098615 |                         |                  |             |          |                         |
| 0.102006 | 0.112792 | 0.116729 | 0.098722 | 0.101419 | XXXXXXXXXXXXXXXXXXXXXXX |                  |             |          |                         |
| 0.074172 | 0.080045 | 0.077109 | 0.085917 | 0.077109 |                         |                  |             |          |                         |
| 0.081711 | 0.087683 | 0.084697 | 0.089176 | 0.08619  | USED STUD DESIGN        |                  | t           | F        |                         |
| 0.097323 | 0.10237  | 0.093284 | 0.101361 | 0.098332 |                         | 0.093844         | 0.010497    | -0.16255 | 1.659295                |
| 0.100082 | 0.103017 | 0.099349 | 0.10155  | 0.100082 |                         |                  | NO          | NO       |                         |
| 0.102594 | 0.110543 | 0.106043 | 0.104355 | 0.102006 | XXXXXXXXXXXXXXXXXXXXXXX |                  |             |          |                         |
| MEAN     | 0.095903 | 0.100355 | 0.100401 | 0.098207 | OVERALL                 | 0.09695          |             |          |                         |
| STD DEV  | 0.009082 | 0.009516 | 0.009485 | 0.007719 |                         | 0.008254         |             |          |                         |

TABLE 9; ALLOY M, LUBRICANT NO. 9

| STUD1    | STUD2    | STUD3    | STUD4    | STUD5    | MEAN<br>VALUE              | STD<br>DEVIATION | TEST<br>FOR         |                     | 95% Conf |
|----------|----------|----------|----------|----------|----------------------------|------------------|---------------------|---------------------|----------|
|          |          |          |          |          |                            |                  | MEAN                | VARIANCE            |          |
| 0.077109 | 0.071235 | 0.085917 | 0.085917 | 0.082981 |                            |                  | t-TEST<br>t* = 1.68 | F-TEST<br>F* = 1.98 |          |
| 0.081711 | 0.069762 | 0.083204 | 0.08619  | 0.08619  |                            |                  |                     |                     |          |
| 0.097323 | 0.078131 | 0.091264 | 0.094294 | 0.096313 | RUN-IN                     | 0.08731          | 0.008625            |                     |          |
| 0.096353 | 0.077236 | 0.088708 | 0.082531 | 0.095588 |                            |                  |                     |                     |          |
| 0.100832 | 0.079684 | 0.090848 | 0.096722 | 0.096722 | XXXXXXXXXXXXXXXXXXXX       |                  |                     |                     |          |
| 0.088852 | 0.071235 | 0.074172 | 0.077109 | 0.088852 | DESIGN VS RUN-IN           |                  |                     |                     |          |
| 0.089176 | 0.063785 | 0.071256 | 0.084697 | 0.090668 | t                          |                  |                     | F                   |          |
| 0.101361 | 0.069035 | 0.078131 | 0.091264 | 0.108426 | DESIGN                     | 0.087062         | 0.013904            | 0.076033            | 2.598535 |
| 0.103017 | 0.065757 | 0.08259  | 0.093295 | 0.105217 |                            |                  | NO                  | YES                 |          |
| 0.108293 | 0.074982 | 0.089673 | 0.099658 | 0.106043 | XXXXXXXXXXXXXXXXXXXX       |                  |                     |                     |          |
| 0.074172 | 0.082981 | 0.068297 | 0.085917 | 0.074172 | USED STUD RUN-IN           |                  |                     |                     |          |
| 0.07275  | 0.065279 | 0.075737 | 0.084697 | 0.093653 |                            | 0.087158         | 0.016867            |                     |          |
| 0.080152 | 0.069035 | 0.081163 | 0.10338  | 0.116497 |                            |                  |                     |                     |          |
| 0.078766 | 0.074175 | 0.08259  | 0.115483 | 0.108884 |                            |                  |                     |                     |          |
| 0.081447 | 0.082622 | 0.090848 | 0.127971 | 0.108293 | XXXXXXXXXXXXXXXXXXXX       |                  |                     |                     |          |
| 0.077109 | 0.082981 | 0.071235 | 0.091787 | 0.085917 | DESIGN VS USED STUD DESIGN |                  |                     |                     |          |
| 0.078724 | 0.075737 | 0.071256 | 0.089176 | 0.08619  | t                          |                  |                     | F                   |          |
| 0.086214 | 0.084194 | 0.069035 | 0.107417 | 0.091264 | USED STUD DESIGN           | 0.085095         | 0.013215            | -0.5127             | 1.106859 |
| 0.084884 | 0.079531 | 0.063461 | 0.111084 | 0.088708 |                            |                  | NO                  | NO                  |          |
| 0.090848 | 0.084385 | 0.065794 | 0.118415 | 0.092023 | XXXXXXXXXXXXXXXXXXXX       |                  |                     |                     |          |
|          |          |          |          |          | OVERALL                    |                  |                     |                     |          |
| MEAN     | 0.087455 | 0.075088 | 0.082293 | 0.09885  |                            | 0.086656         |                     |                     | 0.013305 |
| STD DEV  | 0.01059  | 0.006685 | 0.007473 | 0.013253 |                            |                  |                     |                     | 0.010711 |

TABLE 10; ALLOY M, LUBRICANT 10

| STUD1    | STUD2    | STUD3    | STUD4    | STUD5    | MEAN<br>VALUE           | STD<br>DEVIATION | TEST<br>FOR                |           | 95% Confl |
|----------|----------|----------|----------|----------|-------------------------|------------------|----------------------------|-----------|-----------|
|          |          |          |          |          |                         |                  | MEAN                       | VARIANCE  |           |
| 0.097655 | 0.080045 | 0.082981 | 0.091787 | 0.085917 |                         |                  | t-TEST                     | F-TEST    |           |
| 0.090668 | 0.083204 | 0.083204 | 0.092161 | 0.081711 |                         |                  | t* = 1.68                  | F* = 1.98 |           |
| 0.088234 | 0.086214 | 0.085204 | 0.106408 | 0.083183 | RUN-IN                  | 0.088            |                            |           |           |
| 0.084884 | 0.08412  | 0.080295 | 0.106684 | 0.080295 |                         |                  |                            |           |           |
| 0.086736 | 0.085561 | 0.081447 | 0.110543 | 0.080859 | XXXXXXXXXXXXXXXXXXXXXXX |                  |                            |           |           |
| 0.085917 | 0.085917 | 0.074172 | 0.080045 | 0.074172 |                         |                  | DESIGN VS RUN-IN           |           |           |
| 0.077231 | 0.075737 | 0.080218 | 0.080218 | 0.074243 |                         |                  | t                          | F         |           |
| 0.078131 | 0.071057 | 0.077121 | 0.083183 | 0.078131 | DESIGN                  | 0.075242         | 0.006183                   | 6.010842  | 1.946174  |
| 0.071115 | 0.065757 | 0.068053 | 0.080295 | 0.069584 |                         |                  | YES                        | NO        |           |
| 0.068857 | 0.06702  | 0.066407 | 0.081447 | 0.06702  | XXXXXXXXXXXXXXXXXXXXXXX |                  |                            |           |           |
| 0.088852 | 0.077109 | 0.074172 | 0.080045 | 0.077109 |                         |                  |                            |           |           |
| 0.089762 | 0.07275  | 0.075737 | 0.077231 | 0.075737 | USED STUD RUN-IN        |                  |                            |           |           |
| 0.066002 | 0.072067 | 0.07611  | 0.077121 | 0.072067 |                         | 0.071922         | 0.006786                   |           |           |
| 0.059633 | 0.069584 | 0.069584 | 0.07188  | 0.063461 |                         |                  |                            |           |           |
| 0.056603 | 0.06947  | 0.070082 | 0.072532 | 0.063344 | XXXXXXXXXXXXXXXXXXXXXXX |                  |                            |           |           |
| 0.074172 | 0.071235 | 0.074172 | 0.077109 | 0.077109 |                         |                  | DESIGN VS USED STUD DESIGN |           |           |
| 0.07275  | 0.07275  | 0.075737 | 0.077231 | 0.074243 | USED STUD DESIGN        |                  | t                          | F         |           |
| 0.069035 | 0.07611  | 0.0751   | 0.079142 | 0.071057 |                         | 0.071423         | 0.005077                   | -2.38675  | 1.483318  |
| 0.060399 | 0.069584 | 0.068819 | 0.069584 | 0.068819 |                         |                  | YES                        | NO        |           |
| 0.058442 | 0.068857 | 0.068245 | 0.071307 | 0.064569 | XXXXXXXXXXXXXXXXXXXXXXX |                  |                            |           |           |
|          |          |          |          |          | OVERALL                 |                  |                            |           |           |
| MEAN     | 0.075254 | 0.075207 | 0.076319 | 0.083298 |                         | 0.076647         |                            | 0.009502  |           |
| STD DEV  | 0.012049 | 0.006737 | 0.005911 | 0.012058 |                         |                  |                            | 0.00662   |           |

## **ATTACHMENT III**

### **Phase I - Coefficient of Friction Dataset**

#### **AISI 4140 Phosphate Coated**

The main body of the following tables list each individual calculated coefficient of friction value, based on the equation of Appendix A, for every AISI 4140 stud tested. The mean coefficient of friction and standard deviations for each individual stud is provided at the bottom of the table, while the mean coefficient of friction, standard deviation and the results of the statistical tests performed for all studs tested under the same loading sequence are provided to the right of the individual values.

TABLE 1; ALLOY P, LUBRICANT NO. 1

| STUD1    | STUD2    | STUD3    | STUD4    | STUD5    | MEAN<br>VALUE        | STD<br>DEVIATION | TEST<br>FOR<br>MEAN<br>t-TEST<br>t* = 1.68 | TEST<br>FOR<br>VARIANCE<br>F-TEST<br>F* = 1.98 | 95% Conf |
|----------|----------|----------|----------|----------|----------------------|------------------|--|--|----------|
| 0.109049 | 0.100664 | 0.100664 | 0.095072 | 0.095072 |                      |                  |  |  |          |
| 0.105852 | 0.099959 | 0.101383 | 0.097112 | 0.092842 |                      |                  |  |  |          |
| 0.103715 | 0.097933 | 0.105642 | 0.097933 | 0.096005 | RUN-IN               | 0.099195         | 0.00435                                    |  |          |
| 0.101038 | 0.094737 | 0.103838 | 0.096837 | 0.094038 |                      |                  |  |  |          |
| 0.100883 | 0.094627 | 0.103897 | 0.097422 | 0.094088 | XXXXXXXXXXXXXXXXXXXX |                  |  |  |          |
| 0.083884 | 0.081086 | 0.083884 | 0.081088 | 0.07549  |                      |                  |  |  |          |
| 0.094265 | 0.089994 | 0.099959 | 0.091418 | 0.082873 |                      |                  |  |  |          |
| 0.101788 | 0.091185 | 0.105642 | 0.094077 | 0.086364 | DESIGN               | 0.092392         | 0.008488                                   | 3.566561                                       | 3.807644 |
| 0.101038 | 0.091906 | 0.106638 | 0.096837 | 0.087529 |                      |                  |  |  |          |
| 0.100147 | 0.091831 | 0.104968 | 0.097422 | 0.088475 | XXXXXXXXXXXXXXXXXXXX |                  |  |  |          |
| 0.083884 | 0.081086 | 0.083884 | 0.086682 | 0.083884 |                      |                  |  |  |          |
| 0.087146 | 0.089994 | 0.097112 | 0.091418 | 0.084297 | USED STUD RUN-IN     |                  |  |  |          |
| 0.088292 | 0.089257 | 0.101788 | 0.090221 | 0.086364 | 0.089372             | 0.00594          |  |  |          |
| 0.088988 | 0.088258 | 0.103138 | 0.089718 | 0.086069 |                      |                  |  |  |          |
| 0.089035 | 0.087916 | 0.102828 | 0.089584 | 0.083441 | XXXXXXXXXXXXXXXXXXXX |                  |  |  |          |
| 0.072691 | 0.069891 | 0.081086 | 0.07549  | 0.067092 |                      |                  |  |  |          |
| 0.078599 | 0.081448 | 0.089994 | 0.081448 | 0.080024 | USED STUD DESIGN     |                  |  |  |          |
| 0.083471 | 0.084435 | 0.098897 | 0.087328 | 0.080577 | 0.084251             | 0.008641         |  |  |          |
| 0.087529 | 0.088069 | 0.098838 | 0.080447 | 0.079501 |                      |                  |  |  |          |
| 0.089035 | 0.087357 | 0.101754 | 0.09239  | 0.080085 | XXXXXXXXXXXXXXXXXXXX |                  |  |  |          |
|          |          |          |          |          | OVERALL              |                  |  |  |          |
| MEAN     | 0.092496 | 0.088982 | 0.100351 | 0.090988 | 0.085204             | 0.091302         | 0.008845                                   |  |          |
| STD DEV  | 0.009884 | 0.007273 | 0.00713  | 0.006203 | 0.007215             |                  |  |  |          |

DESIGN VS USED STUD DESIGN

t F  
-3.36034 0.965028  
YES NO

TABLE 2: ALLOY P, LUBRICANT NO.2

| STUD1    | STUD2    | STUD3    | STUD4    | STUD5    | MEAN<br>VALUE                | STD<br>DEVIATION | TEST<br>FOR<br>MEAN<br>t*-1.68 | TEST<br>FOR<br>VARIANCE<br>F*-1.98                     | 95% Conf |
|----------|----------|----------|----------|----------|------------------------------|------------------|--------------------------------|--|----------|
| 0.095072 | 0.097868 | 0.086882 | 0.097868 | 0.095072 |                              |                  |                                |  |          |
| 0.099859 | 0.097112 | 0.089994 | 0.098536 | 0.094285 |                              |                  |                                |  |          |
| 0.101788 | 0.096005 | 0.091185 | 0.102751 | 0.094077 | RUN-IN                       | 0.095334         | 0.004539                       |  |          |
| 0.098938 | 0.094036 | 0.089718 | 0.101038 | 0.091177 |                              |                  |                                |  |          |
| 0.100147 | 0.09239  | 0.089594 | 0.098612 | 0.098475 | XXXXXXXXXXXXXXXXXXXXXXXXXXXX |                  |                                |  |          |
| 0.072891 | 0.078288 | 0.078288 | 0.083884 | 0.072891 |                              |                  |                                |  |          |
| 0.080024 | 0.081448 | 0.082873 | 0.091418 | 0.078599 |                              |                  |                                |  |          |
| 0.089257 | 0.085399 | 0.086364 | 0.098889 | 0.093471 | DESIGN                       | 0.085346         | 0.008673                       | DESIGN VS RUN-IN<br>t F<br>6.063918 2.293197           |          |
| 0.091177 | 0.08534  | 0.087629 | 0.098837 | 0.08315  |                              |                  |                                |  |          |
| 0.092949 | 0.085679 | 0.086238 | 0.099076 | 0.094001 | XXXXXXXXXXXXXXXXXXXXXXXXXXXX |                  |                                |  |          |
| 0.081086 | 0.083884 | 0.07549  | 0.096882 | 0.086882 |                              |                  |                                |  |          |
| 0.085722 | 0.085722 | 0.084287 | 0.089994 | 0.089994 | USED STUD RUN-IN             |                  |                                |  |          |
| 0.094077 | 0.089257 | 0.086364 | 0.098897 | 0.091185 |                              | 0.089109         | 0.003368                       |  |          |
| 0.095437 | 0.088258 | 0.089718 | 0.086137 | 0.089718 |                              |                  |                                |  |          |
| 0.099076 | 0.089035 | 0.088475 | 0.094827 | 0.087916 | XXXXXXXXXXXXXXXXXXXXXXXXXXXX |                  |                                |  |          |
| 0.058691 | 0.07549  | 0.084292 | 0.081086 | 0.072891 |                              |                  |                                |  |          |
| 0.0729   | 0.078599 | 0.078599 | 0.091418 | 0.090024 | USED STUD DESIGN             |                  |                                |  |          |
| 0.081542 | 0.083471 | 0.081542 | 0.098005 | 0.084435 |                              | 0.081834         | 0.008563                       | DESIGN VS USED STUD DESIGN<br>t F<br>-1.59912 1.552179 |          |
| 0.08388  | 0.08534  | 0.08388  | 0.095437 | 0.08534  |                              |                  |                                |  |          |
| 0.08512  | 0.082882 | 0.084001 | 0.093608 | 0.085679 | XXXXXXXXXXXXXXXXXXXXXXXXXXXX |                  |                                |  |          |
|          |          |          |          |          | OVERALL                      |                  |                                |  |          |
| MEAN     | 0.087877 | 0.086775 | 0.086187 | 0.094599 | 0.087806                     | 0.008183         |                                |  |          |
| STD DEV  | 0.011254 | 0.008284 | 0.00443  | 0.005896 | 0.00639                      |                  |                                |  |          |

TABLE 3; ALLOY P, LUBRICANT NO. 3

| STUD1    | STUD2    | STUD3    | STUD4    | STUD5    | MEAN<br>VALUE                | STD.<br>DEVIATION | TEST<br>FOR<br>MEAN |          | TEST<br>FOR<br>VARIANCE |          |
|----------|----------|----------|----------|----------|------------------------------|-------------------|---------------------|----------|-------------------------|----------|
|          |          |          |          |          |                              |                   | t-TEST              | F-TEST   | t-TEST                  | F-TEST   |
|          |          |          |          |          |                              |                   | t*=-1.68            | F*=-1.98 | t*=-1.68                | F*=-1.98 |
| 0.07549  | 0.072691 | 0.072691 | 0.081491 | 0.056691 |                              |                   |                     |          |                         |          |
| 0.067199 | 0.070049 | 0.067199 | 0.058844 | 0.057218 |                              |                   |                     |          |                         |          |
| 0.063207 | 0.065138 | 0.062242 | 0.057414 | 0.054517 | RUN-IN                       | 0.060968          | 0.008602            |          |                         |          |
| 0.059053 | 0.060614 | 0.059053 | 0.053939 | 0.052476 |                              |                   |                     |          |                         |          |
| 0.05774  | 0.05949  | 0.053406 | 0.052486 | 0.050154 | XXXXXXXXXXXXXXXXXXXXXXXXXXXX |                   |                     |          |                         |          |
| 0.044682 | 0.053068 | 0.041879 | 0.047484 | 0.039075 |                              |                   |                     |          |                         |          |
| 0.050087 | 0.057218 | 0.050087 | 0.045806 | 0.032961 |                              |                   |                     |          |                         |          |
| 0.049688 | 0.055483 | 0.045824 | 0.04679  | 0.045824 | DESIGN                       | 0.047836          | 0.005083            | 7.727028 | 1.784087                |          |
| 0.051014 | 0.053207 | 0.04736  | 0.048091 | 0.046697 |                              |                   |                     |          |                         |          |
| 0.050738 | 0.051905 | 0.048987 | 0.047819 | 0.044901 | XXXXXXXXXXXXXXXXXXXXXXXXXXXX |                   |                     |          |                         |          |
| 0.050286 | 0.061491 | 0.050286 | 0.050286 | 0.081088 |                              |                   |                     |          |                         |          |
| 0.051513 | 0.058844 | 0.04866  | 0.054366 | 0.035816 | USED STUD RUN-IN             |                   |                     |          |                         |          |
| 0.052586 | 0.05838  | 0.048722 | 0.050654 | 0.048722 | 0.051926                     | 0.007728          |                     |          |                         |          |
| 0.050283 | 0.054669 | 0.048822 | 0.048822 | 0.04736  |                              |                   |                     |          |                         |          |
| 0.048987 | 0.051805 | 0.04957  | 0.04957  | 0.046832 | XXXXXXXXXXXXXXXXXXXXXXXXXXXX |                   |                     |          |                         |          |
| 0.044692 | 0.047494 | 0.061491 | 0.036272 | 0.039075 |                              |                   |                     |          |                         |          |
| 0.047233 | 0.054366 | 0.061496 | 0.04438  | 0.042853 | DESIGN VS USED STUD DESIGN   |                   |                     |          |                         |          |
| 0.04679  | 0.05162  | 0.060311 | 0.04679  | 0.042826 | USED STUD DESIGN             |                   |                     |          |                         |          |
| 0.045897 | 0.050283 | 0.057591 | 0.04736  | 0.042973 | 0.046853                     | 0.006726          | 0.48423             | 1.744486 |                         |          |
| 0.046652 | 0.050184 | 0.056573 | 0.047819 | 0.043149 | XXXXXXXXXXXXXXXXXXXXXXXXXXXX |                   |                     |          |                         |          |
|          |          |          |          |          | OVERALL                      |                   |                     |          |                         |          |
| MEAN     | 0.05269  | 0.05889  | 0.053119 | 0.049814 | 0.052345                     | 0.008387          |                     |          |                         |          |
| STD DEV  | 0.008051 | 0.008624 | 0.008545 | 0.005566 | 0.010295                     |                   |                     |          |                         |          |

TABLE 4: ALLOY P, LUBRICANT NO. 4

| STUD1    | STUD2    | STUD3    | STUD4    | STUD5    | MEAN<br>VALUE          | STD<br>DEVIATION | TEST<br>FOR                |           | 95% Conf |
|----------|----------|----------|----------|----------|------------------------|------------------|----------------------------|-----------|----------|
|          |          |          |          |          |                        |                  | MEAN                       | VARIANCE  |          |
| 0.164868 | 0.150925 | 0.150925 | 0.153714 | 0.150925 |                        |                  | t-TEST                     | F-TEST    |          |
| 0.158658 | 0.152558 | 0.153977 | 0.149718 | 0.155397 |                        |                  | t* = 1.68                  | F* = 1.98 |          |
| 0.158416 | 0.148109 | 0.149955 | 0.14257  | 0.150878 | RUN-IN                 | 0.147838         | 0.007872                   |           |          |
| 0.148377 | 0.144369 | 0.14303  | 0.137003 | 0.14303  |                        |                  |                            |           |          |
| 0.141531 | 0.144146 | 0.137346 | 0.131068 | 0.139982 | XXXXXXXXXXXXXXXXXXXXXX |                  |                            |           |          |
| 0.142558 | 0.131383 | 0.136975 | 0.134184 | 0.142558 |                        |                  | DESIGN VS RUN-IN           |           |          |
| 0.142616 | 0.132671 | 0.141198 | 0.129828 | 0.139775 |                        |                  | t                          | F         |          |
| 0.14267  | 0.133334 | 0.138876 | 0.127791 | 0.139799 | DESIGN                 | 0.138713         | 0.005858                   | 6.332499  | 1.715613 |
| 0.138342 | 0.132314 | 0.137003 | 0.124128 | 0.134993 |                        |                  | YES                        | NO        |          |
| 0.135254 | 0.134207 | 0.133954 | 0.1221   | 0.144689 | XXXXXXXXXXXXXXXXXXXXXX |                  |                            |           |          |
| 0.142558 | 0.131383 | 0.136975 | 0.131383 | 0.136975 |                        |                  |                            |           |          |
| 0.149718 | 0.138354 | 0.146877 | 0.132871 | 0.142816 | USED STUD RUN-IN       |                  |                            |           |          |
| 0.150878 | 0.138876 | 0.143483 | 0.13241  | 0.148109 |                        | 0.139976         | 0.006696                   |           |          |
| 0.147716 | 0.139882 | 0.137872 | 0.130974 | 0.14238  |                        |                  |                            |           |          |
| 0.149375 | 0.137346 | 0.13787  | 0.127404 | 0.148715 | XXXXXXXXXXXXXXXXXXXXXX |                  |                            |           |          |
| 0.142558 | 0.136975 | 0.139766 | 0.131393 | 0.134184 |                        |                  | DESIGN VS USED STUD DESIGN |           |          |
| 0.161075 | 0.149718 | 0.152558 | 0.135513 | 0.148298 | USED STUD DESIGN       |                  | t                          | F         |          |
| 0.166584 | 0.147188 | 0.156416 | 0.134258 | 0.150878 |                        | 0.147925         | 0.01082                    | 4.982035  | 3.411894 |
| 0.160432 | 0.147047 | 0.15374  | 0.132314 | 0.153071 |                        |                  | YES                        | YES       |          |
| 0.16206  | 0.146761 | 0.151467 | 0.138823 | 0.167076 | XXXXXXXXXXXXXXXXXXXXXX |                  |                            |           |          |
|          |          |          |          |          | OVERALL                |                  |                            |           |          |
| MEAN     | 0.150156 | 0.140888 | 0.141724 | 0.133883 |                        | 0.142888         | 0.009478                   |           |          |
| STD DEV  | 0.008533 | 0.007125 | 0.008123 | 0.007827 |                        |                  |                            |           |          |

TABLE 5: ALLOY P, LUBRICANT NO. 5

| STUD1    | STUD2    | STUD3    | STUD4    | STUD5    | MEAN<br>VALUE           | STD<br>DEVIATION | TEST<br>FOR<br>MEAN<br>t-TEST<br>t* = 1.68 | TEST<br>FOR<br>VARIANCE<br>F-TEST<br>F* = 1.96 | 95% Conf       |
|----------|----------|----------|----------|----------|-------------------------|------------------|--|--|----------------|
| 0.095072 | 0.089479 | 0.085072 | 0.081086 | 0.089479 |                         |                  |  |  |                |
| 0.092842 | 0.089994 | 0.085722 | 0.081448 | 0.089994 |                         |                  |  |  |                |
| 0.092149 | 0.082257 | 0.082506 | 0.081642 | 0.082257 | RUN-IN                  | 0.008966         | 0.004936                                   |  |                |
| 0.091177 | 0.089998 | 0.080231 | 0.078771 | 0.082256 | XXXXXXXXXXXXXXXXXXXXXXX |                  |  |  |                |
| 0.089594 | 0.089798 | 0.080085 | 0.080085 | 0.082238 | XXXXXXXXXXXXXXXXXXXXXXX |                  |  |  |                |
| 0.081491 | 0.087092 | 0.081491 | 0.084292 | 0.072691 | DESIGN                  | 0.075851         | 0.0084                                     | DESIGN VS RUN-IN<br>t<br>0.99849               | 1.680901<br>NO |
| 0.074325 | 0.077174 | 0.0729   | 0.070049 | 0.077174 | DESIGN                  | 0.075851         | 0.0084                                     | DESIGN VS RUN-IN<br>t<br>0.99849               | 1.680901<br>NO |
| 0.077683 | 0.082506 | 0.077683 | 0.076753 | 0.077683 | XXXXXXXXXXXXXXXXXXXXXXX |                  |  |  |                |
| 0.081691 | 0.081691 | 0.078771 | 0.076951 | 0.078771 | XXXXXXXXXXXXXXXXXXXXXXX |                  |  |  |                |
| 0.08456  | 0.083441 | 0.078525 | 0.078966 | 0.077267 | XXXXXXXXXXXXXXXXXXXXXXX |                  |  |  |                |
| 0.07549  | 0.087092 | 0.087092 | 0.087092 | 0.072691 | USED STUD RUN-IN        | 0.076041         | 0.005599                                   |  |                |
| 0.07575  | 0.080024 | 0.078599 | 0.071475 | 0.080024 |                         |                  |  |  |                |
| 0.080577 | 0.083364 | 0.081542 | 0.076718 | 0.080577 |                         |                  |  |  |                |
| 0.08315  | 0.08388  | 0.08242  | 0.075851 | 0.078041 | XXXXXXXXXXXXXXXXXXXXXXX |                  |  |  |                |
| 0.085679 | 0.084001 | 0.082882 | 0.078166 | 0.077848 | XXXXXXXXXXXXXXXXXXXXXXX |                  |  |  |                |
| 0.089891 | 0.087092 | 0.081491 | 0.086891 | 0.087092 | USED STUD DESIGN        | 0.075601         | 0.007141                                   | DESIGN VS USED STUD DESIGN<br>t<br>-0.02603    | 1.244782<br>NO |
| 0.07575  | 0.07575  | 0.088824 | 0.088824 | 0.078599 |                         |                  |  |  |                |
| 0.078612 | 0.081642 | 0.076716 | 0.073824 | 0.080577 |                         |                  |  |  |                |
| 0.081691 | 0.08388  | 0.078591 | 0.07388  | 0.080981 | XXXXXXXXXXXXXXXXXXXXXXX |                  |  |  |                |
| 0.082322 | 0.086798 | 0.080644 | 0.078406 | 0.081204 | XXXXXXXXXXXXXXXXXXXXXXX |                  |  |  |                |
|          |          |          |          |          | OVERALL                 |                  |  |  |                |
| MEAN     | 0.081525 | 0.081642 | 0.079101 | 0.074416 | 0.079085                | 0.007603         |  |  |                |
| STD DEV  | 0.008346 | 0.007365 | 0.007743 | 0.008123 | 0.008595                |                  |  |  |                |

TABLE 6: ALLOY P, LUBRICANT NO. 6

| STUD1    | STUD2    | STUD3    | STUD4    | STUD5    | MEAN<br>VALUE              | STD<br>DEVIATION | TEST<br>FOR<br>MEAN<br>t*-1.68 | TEST<br>FOR<br>VARIANCE<br>F*-1.98 | 95% Conf |
|----------|----------|----------|----------|----------|----------------------------|------------------|--------------------------------|------------------------------------|----------|
| 0.081086 | 0.100684 | 0.095072 | 0.095072 | 0.095072 |                            |                  |                                |                                    |          |
| 0.085722 | 0.092842 | 0.091418 | 0.092842 | 0.092842 |                            |                  |                                |                                    |          |
| 0.084435 | 0.090221 | 0.088292 | 0.092149 | 0.088292 | RUN-IN                     | 0.08919          | 0.004788                       |                                    |          |
| 0.080231 | 0.089718 | 0.087529 | 0.087529 | 0.087529 | XXXXXXXXXXXXXXXXXXXX       |                  |                                |                                    |          |
| 0.081763 | 0.087357 | 0.086798 | 0.087916 | 0.087357 | DESIGN VS RUN-IN           |                  |                                |                                    |          |
| 0.087082 | 0.078288 | 0.081086 | 0.081086 | 0.07849  |                            |                  |                                |                                    |          |
| 0.0729   | 0.081448 | 0.082873 | 0.082873 | 0.077174 |                            |                  |                                |                                    |          |
| 0.071894 | 0.081542 | 0.085399 | 0.085399 | 0.081542 | DESIGN                     | 0.078596         | 0.005128                       | 6.837252                           | 1.147139 |
| 0.07074  | 0.080231 | 0.08315  | 0.08461  | 0.08242  |                            |                  |                                |                                    |          |
| 0.07169  | 0.080085 | 0.084001 | 0.08512  | 0.081763 | XXXXXXXXXXXXXXXXXXXX       |                  |                                |                                    |          |
| 0.078288 | 0.083894 | 0.083894 | 0.089891 | 0.095072 | USED STUD RUN-IN           |                  |                                |                                    |          |
| 0.077174 | 0.087146 | 0.087146 | 0.077174 | 0.089904 | 0.082336                   | 0.005358         |                                |                                    |          |
| 0.078612 | 0.085399 | 0.086384 | 0.078718 | 0.085399 |                            |                  |                                |                                    |          |
| 0.077311 | 0.08242  | 0.08534  | 0.077311 | 0.08461  | XXXXXXXXXXXXXXXXXXXX       |                  |                                |                                    |          |
| 0.077848 | 0.082882 | 0.08456  | 0.077848 | 0.08512  | DESIGN VS USED STUD DESIGN |                  |                                |                                    |          |
| 0.072691 | 0.07649  | 0.078288 | 0.072691 | 0.072691 |                            |                  |                                |                                    |          |
| 0.071475 | 0.081448 | 0.085722 | 0.078599 | 0.077174 | USED STUD DESIGN           |                  |                                |                                    |          |
| 0.074789 | 0.082506 | 0.086384 | 0.078648 | 0.083471 | 0.07922                    | 0.005013         | -0.28202                       | 1.046526                           |          |
| 0.07293  | 0.08242  | 0.08534  | 0.078581 | 0.08461  |                            |                  |                                |                                    |          |
| 0.074489 | 0.08512  | 0.085679 | 0.077287 | 0.084001 | XXXXXXXXXXXXXXXXXXXX       |                  |                                |                                    |          |
| MEAN     | 0.076208 | 0.084556 | 0.086194 | 0.081867 | OVERALL                    |                  |                                |                                    |          |
| STD DEV  | 0.004938 | 0.005655 | 0.003527 | 0.008823 | 0.082585                   | 0.006413         |                                |                                    |          |

TABLE 7: ALLOY P, LUBRICANT NO. 7

| STUD1    | STUD2    | STUD3    | STUD4    | STUD5    | MEAN<br>VALUE              | STD<br>DEVIATION | TEST<br>FOR<br>MEAN<br>t*-1.68 | TEST<br>FOR<br>VARIANCE<br>F*-1.98 | 95% Conf |
|----------|----------|----------|----------|----------|----------------------------|------------------|--------------------------------|------------------------------------|----------|
| 0.114637 | 0.131393 | 0.117431 | 0.114637 | 0.109049 |                            |                  |                                |                                    |          |
| 0.111343 | 0.121296 | 0.108497 | 0.112765 | 0.111343 |                            |                  |                                |                                    |          |
| 0.108532 | 0.110459 | 0.104878 | 0.109496 | 0.106532 | RUN-IN                     | 0.108794         | 0.0074                         |                                    |          |
| 0.109236 | 0.106636 | 0.098636 | 0.103136 | 0.104536 |                            |                  |                                |                                    |          |
| 0.10229  | 0.103997 | 0.087422 | 0.100893 | 0.10229  | XXXXXXXXXXXXXXXXXXXXXXX    |                  |                                |                                    |          |
| 0.100664 | 0.114637 | 0.103459 | 0.111843 | 0.106254 |                            |                  |                                |                                    |          |
| 0.102806 | 0.114188 | 0.104229 | 0.107075 | 0.108497 |                            |                  |                                |                                    |          |
| 0.105642 | 0.119127 | 0.103715 | 0.108496 | 0.108496 | DESIGN VS RUN-IN           |                  |                                |                                    |          |
| 0.108037 | 0.113635 | 0.101036 | 0.101036 | 0.108037 | DESIGN                     | 0.10726          | 0.00478                        | 0.870828                           | 2.398463 |
| 0.104433 | 0.110323 | 0.10229  | 0.104433 | 0.10711  | NO                         |                  |                                |                                    |          |
| 0.111843 | 0.126601 | 0.123017 | 0.111843 | 0.111843 | XXXXXXXXXXXXXXXXXXXXXXX    |                  |                                |                                    |          |
| 0.111343 | 0.124142 | 0.114188 | 0.107075 | 0.111343 | USED STUD RUN-IN           |                  |                                |                                    |          |
| 0.115275 | 0.122015 | 0.109496 | 0.103715 | 0.112365 | 0.111957                   | 0.006866         |                                |                                    |          |
| 0.110837 | 0.115734 | 0.106636 | 0.103636 | 0.108737 |                            |                  |                                |                                    |          |
| 0.108181 | 0.111183 | 0.106576 | 0.100883 | 0.107646 | XXXXXXXXXXXXXXXXXXXXXXX    |                  |                                |                                    |          |
| 0.114637 | 0.114637 | 0.128601 | 0.100864 | 0.111843 |                            |                  |                                |                                    |          |
| 0.111343 | 0.11561  | 0.111343 | 0.102806 | 0.111343 | DESIGN VS USED STUD DESIGN |                  |                                |                                    |          |
| 0.113348 | 0.117201 | 0.110459 | 0.106606 | 0.110459 | USED STUD DESIGN           | 0.111977         | 0.005568                       | 3.213689                           | 1.358919 |
| 0.115734 | 0.117633 | 0.110137 | 0.106636 | 0.110137 | YES                        |                  |                                |                                    |          |
| 0.11183  | 0.118353 | 0.108717 | 0.106575 | 0.112465 | XXXXXXXXXXXXXXXXXXXXXXX    |                  |                                |                                    |          |
|          |          |          |          |          | OVERALL                    |                  |                                |                                    |          |
|          |          |          |          |          | 0.109997                   | 0.006433         |                                |                                    |          |
| MEAN     | 0.109405 | 0.116583 | 0.108821 | 0.106262 | 0.109167                   |                  |                                |                                    |          |
| STD DEV  | 0.004596 | 0.008751 | 0.006894 | 0.004326 | 0.0027                     |                  |                                |                                    |          |

TABLE 8: ALLOY P, LUBRICANT NO.8

| STUD1    | STUD2    | STUD3    | STUD4    | STUD5    | MEAN<br>VALUE        | STD<br>DEVIATION | TEST<br>FOR<br>MEAN<br>t*-1.68 | TEST<br>FOR<br>VARIANCE<br>F*-1.98 | 95% Conf |
|----------|----------|----------|----------|----------|----------------------|------------------|--------------------------------|------------------------------------|----------|
| 0.092278 | 0.086882 | 0.089479 | 0.083884 | 0.095072 |                      |                  |                                |                                    |          |
| 0.084297 | 0.084297 | 0.089894 | 0.084297 | 0.086889 |                      |                  |                                |                                    |          |
| 0.083471 | 0.084435 | 0.088292 | 0.087328 | 0.096005 | RUN-IN               | 0.004307         |                                |                                    |          |
| 0.08368  | 0.08368  | 0.087529 | 0.086089 | 0.094737 |                      |                  |                                |                                    |          |
| 0.082882 | 0.08456  | 0.08512  | 0.086798 | 0.092949 | XXXXXXXXXXXXXXXXXXXX |                  |                                |                                    |          |
| 0.081086 | 0.078288 | 0.083884 | 0.081086 | 0.081086 |                      |                  |                                |                                    |          |
| 0.08857  | 0.082873 | 0.085722 | 0.089894 | 0.08857  |                      |                  |                                |                                    |          |
| 0.087328 | 0.088292 | 0.089257 | 0.095041 | 0.090005 | DESIGN               | 0.005334         | -0.89631                       | 1.533241                           |          |
| 0.089718 | 0.090447 | 0.087529 | 0.094038 | 0.096137 |                      |                  | NO                             | NO                                 |          |
| 0.09239  | 0.092849 | 0.087529 | 0.095188 | 0.096304 | XXXXXXXXXXXXXXXXXXXX |                  |                                |                                    |          |
| 0.097868 | 0.089479 | 0.089479 | 0.083884 | 0.083884 |                      |                  |                                |                                    |          |
| 0.094285 | 0.089894 | 0.087148 | 0.087148 | 0.092842 | USED STUD RUN-IN     |                  |                                |                                    |          |
| 0.091185 | 0.090221 | 0.090221 | 0.089257 | 0.088897 |                      | 0.004388         |                                |                                    |          |
| 0.089718 | 0.091177 | 0.089718 | 0.088258 | 0.100338 |                      |                  |                                |                                    |          |
| 0.091272 | 0.094627 | 0.091831 | 0.089035 | 0.100147 | XXXXXXXXXXXXXXXXXXXX |                  |                                |                                    |          |
| 0.100684 | 0.081086 | 0.081086 | 0.081086 | 0.072891 |                      |                  |                                |                                    |          |
| 0.094265 | 0.08857  | 0.082873 | 0.081448 | 0.087148 | USED STUD DESIGN     |                  |                                |                                    |          |
| 0.093113 | 0.090221 | 0.084435 | 0.090221 | 0.083113 |                      | 0.000087         | 0.628202                       | 1.71194                            |          |
| 0.093338 | 0.094038 | 0.090447 | 0.095437 | 0.098437 |                      |                  | NO                             | NO                                 |          |
| 0.097981 | 0.085745 | 0.09239  | 0.088745 | 0.098612 | XXXXXXXXXXXXXXXXXXXX |                  |                                |                                    |          |
|          |          |          |          |          | OVERALL              |                  |                                |                                    |          |
|          |          |          |          |          |                      | 0.005439         |                                |                                    |          |
| MEAN     | 0.090478 | 0.088093 | 0.088543 | 0.088282 |                      | 0.002833         |                                |                                    |          |
| STD DEV  | 0.005419 | 0.004716 | 0.002453 | 0.004897 |                      | 0.00701          |                                |                                    |          |

TABLE 9: ALLOY P, LUBRICANT NO. 9

| STUD1    | STUD2    | STUD3    | STUD4    | STUD5    | MEAN<br>VALUE        | STD<br>DEVIATION | TEST<br>FOR<br>MEAN<br>t-TEST<br>t* = 1.68 | TEST<br>FOR<br>VARIANCE<br>F-TEST<br>F* = 1.98 | 95% Conf |
|----------|----------|----------|----------|----------|----------------------|------------------|--|--|----------|
| 0.097968 | 0.100864 | 0.083884 | 0.108049 | 0.089479 |                      |                  |  |  |          |
| 0.108497 | 0.108497 | 0.078598 | 0.124142 | 0.089994 |                      |                  |  |  |          |
| 0.113348 | 0.113348 | 0.080577 | 0.131486 | 0.097833 | RUN-IN               | 0.108612         | 0.018168                                   |  |          |
| 0.117133 | 0.116734 | 0.079601 | 0.134993 | 0.090637 | XXXXXXXXXXXXXXXXXXXX |                  |  |  |          |
| 0.12317  | 0.124775 | 0.080644 | 0.138916 | 0.101219 | XXXXXXXXXXXXXXXXXXXX |                  |  |  |          |
| 0.108049 | 0.089479 | 0.081088 | 0.117431 | 0.086682 |                      |                  |  |  |          |
| 0.11561  | 0.092842 | 0.07575  | 0.126885 | 0.08857  |                      |                  |  |  |          |
| 0.122878 | 0.098897 | 0.074789 | 0.124903 | 0.090221 | DESIGN               | 0.102122         | 0.020334                                   | DESIGN VS RUN-IN<br>t                          | F        |
| 0.131644 | 0.105238 | 0.07366  | 0.124827 | 0.087529 |                      |                  |  | 0.838843                                       | 1.282716 |
| 0.135777 | 0.109788 | 0.07337  | 0.128357 | 0.089594 | XXXXXXXXXXXXXXXXXXXX |                  |  | NO   | NO       |
| 0.095072 | 0.072891 | 0.072891 | 0.083884 | 0.089891 |                      |                  |  |  |          |
| 0.111343 | 0.084297 | 0.088824 | 0.097112 | 0.07875  | USED STUD RUN-IN     |                  |  |  |          |
| 0.118238 | 0.094077 | 0.087068 | 0.098897 | 0.078612 | 0.08899              | 0.017279         |  |  |          |
| 0.112836 | 0.096137 | 0.087088 | 0.083336 | 0.081691 | XXXXXXXXXXXXXXXXXXXX |                  |  |  |          |
| 0.127828 | 0.098863 | 0.088239 | 0.108717 | 0.08456  |                      |                  |  |  |          |
| 0.103459 | 0.082276 | 0.078288 | 0.088882 | 0.081086 |                      |                  |  |  |          |
| 0.108652 | 0.088536 | 0.082873 | 0.097112 | 0.085722 | USED STUD DESIGN     |                  |  |  |          |
| 0.107569 | 0.088897 | 0.078612 | 0.102751 | 0.094435 | t                    | 0.094438         | 0.011151                                   | -1.85705                                       | 3.325182 |
| 0.108037 | 0.087538 | 0.081691 | 0.108037 | 0.089718 |                      |                  |  | NO   | YES      |
| 0.110859 | 0.095188 | 0.078406 | 0.113536 | 0.092849 | XXXXXXXXXXXXXXXXXXXX |                  |  |  |          |
|          |          |          |          |          | OVERALL              |                  |  |  |          |
| MEAN     | 0.113708 | 0.099288 | 0.075036 | 0.112458 | 0.08779              | 0.018038         |  |  |          |
| STD DEV  | 0.010537 | 0.011546 | 0.00557  | 0.01636  | 0.007423             |                  |  |  |          |

TABLE 10; ALLOY P, LUBRICANT 10

| STUD1    | STUD2    | STUD3    | STUD4    | STUD5    | MEAN<br>VALUE           | STD<br>DEVIATION | TEST<br>FOR |          | TEST<br>FOR<br>VARIANCE | 95% Conf |
|----------|----------|----------|----------|----------|-------------------------|------------------|-------------|----------|-------------------------|----------|
|          |          |          |          |          |                         |                  | t-TEST      | F-TEST   |                         |          |
| 0.092276 | 0.086882 | 0.086882 | 0.117431 | 0.069479 |                         |                  | t*=-1.68    | F*=1.98  |                         |          |
| 0.091418 | 0.081448 | 0.089984 | 0.101383 | 0.069984 |                         |                  |             |          |                         |          |
| 0.080221 | 0.079612 | 0.086364 | 0.082149 | 0.091185 | RUN-IN                  | 0.089188         | 0.007808    |          |                         |          |
| 0.090447 | 0.078041 | 0.08534  | 0.086789 | 0.090447 |                         |                  |             |          |                         |          |
| 0.084827 | 0.077846 | 0.08512  | 0.084001 | 0.080713 | XXXXXXXXXXXXXXXXXXXXXXX |                  |             |          |                         |          |
| 0.081086 | 0.072891 | 0.083884 | 0.086072 | 0.081086 |                         |                  |             |          |                         |          |
| 0.084297 | 0.081448 | 0.078598 | 0.085722 | 0.084297 |                         |                  |             |          |                         |          |
| 0.084435 | 0.082506 | 0.081542 | 0.083471 | 0.087328 | DESIGN                  | 0.083461         | 0.004521    | 3.144089 | 3.088247                | YES      |
| 0.086789 | 0.080231 | 0.08242  | 0.079501 | 0.086988 |                         |                  | YES         |          |                         | YES      |
| 0.086238 | 0.080085 | 0.083441 | 0.078525 | 0.091831 | XXXXXXXXXXXXXXXXXXXXXXX |                  |             |          |                         |          |
| 0.078288 | 0.088891 | 0.07549  | 0.081086 | 0.081086 |                         |                  |             |          |                         |          |
| 0.080024 | 0.074325 | 0.077174 | 0.078599 | 0.080024 | USED STUD RUN-IN        |                  |             |          |                         |          |
| 0.079812 | 0.077683 | 0.080677 | 0.078646 | 0.084435 |                         | 0.077648         | 0.003413    |          |                         |          |
| 0.075851 | 0.075121 | 0.075851 | 0.075121 | 0.08315  |                         |                  |             |          |                         |          |
| 0.075606 | 0.073929 | 0.075608 | 0.07281  | 0.081204 | XXXXXXXXXXXXXXXXXXXXXXX |                  |             |          |                         |          |
| 0.072691 | 0.067082 | 0.072691 | 0.07549  | 0.088891 |                         |                  |             |          |                         |          |
| 0.080024 | 0.078599 | 0.07575  | 0.080024 | 0.081448 | USED STUD DESIGN        |                  |             |          |                         |          |
| 0.079812 | 0.080577 | 0.079812 | 0.083471 | 0.086364 |                         | 0.078505         | 0.004577    | -3.8519  | 1.024934                | YES      |
| 0.080231 | 0.078771 | 0.078041 | 0.080861 | 0.08534  |                         |                  |             |          |                         | NO       |
| 0.076727 | 0.076727 | 0.078525 | 0.077846 | 0.08512  | XXXXXXXXXXXXXXXXXXXXXXX |                  |             |          |                         |          |
|          |          |          |          |          | OVERALL                 |                  |             |          |                         |          |
| MEAN     | 0.083026 | 0.077865 | 0.081872 | 0.084455 | 0.0822                  | 0.00703          |             |          |                         |          |
| STD DEV  | 0.006299 | 0.004529 | 0.004547 | 0.010417 | 0.005281                |                  |             |          |                         |          |

## **ATTACHMENT IV**

### **Phase I - Coefficient of Friction Dataset**

#### **AISI 4140 Alloy Steel (B7)**

The main body of the following tables list each individual calculated coefficient of friction value, based on the equation of Appendix A, for every AISI 4140 stud tested. The mean coefficient of friction and standard deviations for each individual stud is provided at the bottom of the table, while the mean coefficient of friction, standard deviation and the results of the statistical tests performed for all studs tested under the same loading sequence are provided to the right of the individual values.

TABLE 1: ALLOY A, LUBRICANT NO.1

| STUD1    | STUD2    | STUD3    | STUD4 | STUD5 | MEAN<br>VALUE                | STD<br>DEVIATION | TEST<br>FOR<br>MEAN<br>t-TEST<br>t*=1.734 | TEST<br>FOR<br>VARIANCE<br>F-TEST<br>F*=3.18 | 95% Confidence |
|----------|----------|----------|-------|-------|------------------------------|------------------|---|--|----------------|
| 0.114637 | 0.114637 | ERR      | ERR   | ERR   | RUN-IN                       | 0.116372         | 0.00414                                   |  |                |
| 0.118454 | 0.118454 | ERR      | ERR   | ERR   | XXXXXXXXXXXXXXXXXXXXXXXXXXXX |                  |   |  |                |
| 0.115275 | 0.121052 | ERR      | ERR   | ERR   | DESIGN                       | 0.100011         | 0.007379                                  | 6.115088                                     | 3.176365       |
| 0.110837 | 0.120631 | ERR      | ERR   | ERR   | DESIGN VS RUN-IN             |                  |   |  |                |
| 0.109252 | 0.120494 | ERR      | ERR   | ERR   | t                            |                  |   |  |                |
| 0.089479 | 0.089479 | ERR      | ERR   | ERR   | F                            |                  |   |  |                |
| 0.101363 | 0.095689 | ERR      | ERR   | ERR   | Yes                          |                  |   |  |                |
| 0.100824 | 0.103715 | ERR      | ERR   | ERR   | No                           |                  |   |  |                |
| 0.099638 | 0.109437 | ERR      | ERR   | ERR   | XXXXXXXXXXXXXXXXXXXXXXXXXXXX |                  |   |  |                |
| 0.09854  | 0.111193 | ERR      | ERR   | ERR   | USED STUD RUN-IN             |                  |   |  |                |
| 0.109049 | 0.109049 | ERR      | ERR   | ERR   | 0.107416                     | 0.002308         |   |  |                |
| 0.108497 | 0.10992  | ERR      | ERR   | ERR   | XXXXXXXXXXXXXXXXXXXXXXXXXXXX |                  |   |  |                |
| 0.110459 | 0.106605 | ERR      | ERR   | ERR   | DESIGN VS USED STUD DESIGN   |                  |   |  |                |
| 0.105938 | 0.105238 | ERR      | ERR   | ERR   | t                            |                  |   |  |                |
| 0.103361 | 0.106039 | ERR      | ERR   | ERR   | F                            |                  |   |  |                |
| 0.089479 | 0.089479 | ERR      | ERR   | ERR   | USED STUD DESIGN             |                  |   |  |                |
| 0.092842 | 0.097112 | ERR      | ERR   | ERR   | 0.095808                     | 0.004266         | -1.55939                                  | 2.991219                                     |                |
| 0.095041 | 0.098897 | ERR      | ERR   | ERR   | No                           |                  |   |  |                |
| 0.096137 | 0.101038 | ERR      | ERR   | ERR   | XXXXXXXXXXXXXXXXXXXXXXXXXXXX |                  |   |  |                |
| 0.096304 | 0.101754 | ERR      | ERR   | ERR   | OVERALL                      |                  |   |  |                |
|          |          |          |       |       | 0.104902                     | 0.0092           |   |  |                |
| MEAN     | 0.103271 | 0.106533 | ERR   | ERR   |                              |                  |   |  |                |
| STD DEV  | 0.008638 | 0.009671 | ERR   | ERR   |                              |                  |   |  |                |

TABLE 2; ALLOY A, LUBRICANT NO. 2

| STUD1    | STUD2    | STUD3    | STUD4 | STUD5 | MEAN<br>VALUE              | STD<br>DEVIATION     | TEST<br>FOR<br>MEAN | VARIANCE | TEST<br>FOR<br>F-TEST | 95% Confidence |
|----------|----------|----------|-------|-------|----------------------------|----------------------|---------------------|----------|-----------------------|----------------|
| 0.103459 | 0.089479 | ERR      | ERR   | ERR   | ERR                        | ERR                  | t-TEST              | F-TEST   | t*                    | F*             |
| 0.104229 | 0.101383 | ERR      | ERR   | ERR   | 0.101114                   | 0.004544             | t*                  | F*       | 1.734                 | 3.18           |
| 0.105642 | 0.098897 | ERR      | ERR   | ERR   | RUN-IN                     |                      |                     |          |                       |                |
| 0.103138 | 0.100338 | ERR      | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |          |                       |                |
| 0.103361 | 0.101219 | ERR      | ERR   | ERR   | DESIGN                     | 0.095944             | 0.010072            | 1.479751 | 4.913217              |                |
| 0.089479 | 0.072691 | ERR      | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |          |                       |                |
| 0.092842 | 0.089994 | ERR      | ERR   | ERR   | DESIGN VS RUN-IN           |                      |                     |          |                       |                |
| 0.09986  | 0.098897 | ERR      | ERR   | ERR   | t                          |                      |                     |          |                       |                |
| 0.103838 | 0.102438 | ERR      | ERR   | ERR   | No                         |                      |                     |          |                       |                |
| 0.106039 | 0.103361 | ERR      | ERR   | ERR   | Yes                        |                      |                     |          |                       |                |
| 0.095072 | 0.072691 | ERR      | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |          |                       |                |
| 0.099959 | 0.082873 | ERR      | ERR   | ERR   | USED STUD RUN-IN           |                      |                     |          |                       |                |
| 0.104678 | 0.089257 | ERR      | ERR   | ERR   | 0.093908                   | 0.009931             |                     |          |                       |                |
| 0.102438 | 0.094036 | ERR      | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |          |                       |                |
| 0.101754 | 0.096304 | ERR      | ERR   | ERR   | DESIGN VS USED STUD DESIGN |                      |                     |          |                       |                |
| 0.081086 | 0.069891 | ERR      | ERR   | ERR   | t                          |                      |                     |          |                       |                |
| 0.089994 | 0.082873 | ERR      | ERR   | ERR   | Yes                        |                      |                     |          |                       |                |
| 0.093113 | 0.087328 | ERR      | ERR   | ERR   | USED STUD DESIGN           |                      |                     |          |                       |                |
| 0.095437 | 0.092636 | ERR      | ERR   | ERR   | 0.086497                   | 0.00853              | -1.78429            | 1.394303 |                       |                |
| 0.09854  | 0.094068 | ERR      | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |          |                       |                |
| MEAN     | 0.098698 | 0.091033 | ERR   | ERR   | OVERALL                    |                      |                     |          |                       |                |
| STD DEV  | 0.006671 | 0.010324 | ERR   | ERR   | 0.094865                   | 0.009417             |                     |          |                       |                |

TABLE 3: ALLOY A, LUBRICANT NO. 3

| STUD1    | STUD2    | STUD3    | STUD4 | STUD5 | MEAN<br>VALUE              | STD<br>DEVIATION     | TEST<br>FOR<br>MEAN | TEST<br>FOR<br>VARIANCE | F-TEST    | 95% Confidence |
|----------|----------|----------|-------|-------|----------------------------|----------------------|---------------------|-------------------------|-----------|----------------|
| 0.086882 | 0.067092 | ERR      | ERR   | ERR   | RUN-IN                     | 0.070654             | 0.008133            | t-TEST<br>t* = 1.734    | F* = 3.18 |                |
| 0.080024 | 0.065773 | ERR      | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |                         |           |                |
| 0.075753 | 0.065138 | ERR      | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |                         |           |                |
| 0.07074  | 0.061245 | ERR      | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |                         |           |                |
| 0.07169  | 0.062408 | ERR      | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |                         |           |                |
| 0.061491 | 0.050286 | ERR      | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |                         |           |                |
| 0.064348 | 0.051513 | ERR      | ERR   | ERR   | DESIGN                     | 0.056909             | 0.005939            | DESIGN VS RUN-IN<br>t   | F         |                |
| 0.062242 | 0.05162  | ERR      | ERR   | ERR   | DESIGN                     | 0.056909             | 0.005939            | 4.316342                | 1.875367  |                |
| 0.060514 | 0.051014 | ERR      | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     | Yes                     | No        |                |
| 0.063573 | 0.052488 | ERR      | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |                         |           |                |
| 0.058691 | 0.050286 | ERR      | ERR   | ERR   | USED STUD RUN-IN           |                      |                     |                         |           |                |
| 0.061496 | 0.051513 | ERR      | ERR   | ERR   | 0.056942                   | 0.008226             |                     |                         |           |                |
| 0.085138 | 0.048722 | ERR      | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |                         |           |                |
| 0.067088 | 0.048091 | ERR      | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |                         |           |                |
| 0.068822 | 0.04957  | ERR      | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |                         |           |                |
| 0.050286 | 0.047484 | ERR      | ERR   | ERR   | DESIGN VS USED STUD DESIGN |                      |                     |                         |           |                |
| 0.054366 | 0.047233 | ERR      | ERR   | ERR   | t                          |                      |                     | F                       |           |                |
| 0.056449 | 0.047756 | ERR      | ERR   | ERR   | USED STUD DESIGN           | 0.052021             | 0.005314            | -1.93953                | 1.249019  |                |
| 0.058322 | 0.048091 | ERR      | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     | Yes                     | No        |                |
| 0.061823 | 0.048403 | ERR      | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |                         |           |                |
| MEAN     | 0.064977 | 0.053286 | ERR   | ERR   | OVERALL                    | 0.059132             | 0.009749            |                         |           |                |
| STD DEV  | 0.008766 | 0.006804 | ERR   | ERR   |                            |                      |                     |                         |           |                |

TABLE 4; ALLOY A, LUBRICANT NO. 4

| STUD1    | STUD2    | STUD3 | STUD4 | STUD5 | MEAN<br>VALUE    | STD<br>DEVIATION     | TEST<br>FOR<br>MEAN | TEST<br>FOR<br>VARIANCE    | F-TEST<br>F*=3.18 | 95% Confidence |
|----------|----------|-------|-------|-------|------------------|----------------------|---------------------|----------------------------|-------------------|----------------|
| 0.15929  | 0.156502 | ERR   | ERR   | ERR   | RUN-IN           | 0.152273             | 0.00647             |                            |                   |                |
| 0.161075 | 0.152558 | ERR   | ERR   | ERR   | XXXXXX           | XXXXXXXXXXXXXXXXXXXX |                     |                            |                   |                |
| 0.157339 | 0.151801 | ERR   | ERR   | ERR   | XXXXXX           | XXXXXXXXXXXXXXXXXXXX |                     |                            |                   |                |
| 0.151063 | 0.146377 | ERR   | ERR   | ERR   | XXXXXX           | XXXXXXXXXXXXXXXXXXXX |                     |                            |                   |                |
| 0.145715 | 0.141008 | ERR   | ERR   | ERR   | XXXXXX           | XXXXXXXXXXXXXXXXXXXX |                     |                            |                   |                |
| 0.145346 | 0.142556 | ERR   | ERR   | ERR   | XXXXXX           | XXXXXXXXXXXXXXXXXXXX |                     |                            |                   |                |
| 0.151138 | 0.146877 | ERR   | ERR   | ERR   | XXXXXX           | XXXXXXXXXXXXXXXXXXXX |                     |                            |                   |                |
| 0.140723 | 0.141646 | ERR   | ERR   | ERR   | DESIGN           | 0.141301             | 0.005845            | DESIGN VS RUN-IN           |                   |                |
| 0.139682 | 0.137672 | ERR   | ERR   | ERR   |                  |                      | 4.040898            | 1.313249                   |                   |                |
| 0.135777 | 0.131591 | ERR   | ERR   | ERR   | XXXXXX           | XXXXXXXXXXXXXXXXXXXX |                     |                            |                   |                |
| 0.150925 | 0.150925 | ERR   | ERR   | ERR   | XXXXXX           | XXXXXXXXXXXXXXXXXXXX |                     |                            |                   |                |
| 0.151138 | 0.156817 | ERR   | ERR   | ERR   | USED STUD RUN-IN |                      |                     |                            |                   |                |
| 0.150878 | 0.150878 | ERR   | ERR   | ERR   |                  | 0.148261             | 0.005288            |                            |                   |                |
| 0.145038 | 0.145038 | ERR   | ERR   | ERR   | XXXXXX           | XXXXXXXXXXXXXXXXXXXX |                     |                            |                   |                |
| 0.141008 | 0.139962 | ERR   | ERR   | ERR   | XXXXXX           | XXXXXXXXXXXXXXXXXXXX |                     |                            |                   |                |
| 0.142556 | 0.156502 | ERR   | ERR   | ERR   | XXXXXX           | XXXXXXXXXXXXXXXXXXXX |                     |                            |                   |                |
| 0.148298 | 0.151138 | ERR   | ERR   | ERR   | USED STUD DESIGN |                      |                     | DESIGN VS USED STUD DESIGN |                   |                |
| 0.149032 | 0.15457  | ERR   | ERR   | ERR   |                  | 0.148768             | 0.004683            |                            |                   |                |
| 0.145708 | 0.151063 | ERR   | ERR   | ERR   | XXXXXX           | XXXXXXXXXXXXXXXXXXXX |                     |                            |                   |                |
| 0.142577 | 0.146236 | ERR   | ERR   | ERR   | XXXXXX           | XXXXXXXXXXXXXXXXXXXX |                     |                            |                   |                |
| MEAN     | 0.147715 | ERR   | ERR   | ERR   | OVERALL          |                      |                     |                            |                   |                |
| STD DEV  | 0.006637 | ERR   | ERR   | ERR   |                  | 0.147651             | 0.00669             |                            |                   |                |

TABLE 5: ALLOY A, LUBRICANT NO.5

| TABLE 3.1. RESEARCH DESIGN AND DATA ANALYSIS |          |          |       |       |            |               |      |          |  |
|--|----------|----------|-------|-------|------------|---------------|------|----------|--|
| STUD1  | STUD2    | STUD3    | STUD4 | STUD5 | MEAN VALUE | STD DEVIATION | MEAN | VARIANCE |  |
| 0.100664                                     | 0.106254 | ERR      | ERR   | ERR   |            |               |      |          |  |
| 0.097112                                     | 0.104229 | ERR      | ERR   | ERR   |            |               |      |          |  |
| 0.097933                                     | 0.102751 | ERR      | ERR   | ERR   |            |               |      |          |  |
| 0.097538                                     | 0.101038 | ERR      | ERR   | ERR   |            |               |      |          |  |
| 0.100683                                     | 0.10229  | ERR      | ERR   | ERR   |            |               |      |          |  |
| 0.089479                                     | 0.092276 | ERR      | ERR   | ERR   |            |               |      |          |  |
| 0.08657                                      | 0.09959  | ERR      | ERR   | ERR   |            |               |      |          |  |
| 0.091185                                     | 0.103715 | ERR      | ERR   | ERR   |            |               |      |          |  |
| 0.089718                                     | 0.101738 | ERR      | ERR   | ERR   |            |               |      |          |  |
| 0.093508                                     | 0.103361 | ERR      | ERR   | ERR   |            |               |      |          |  |
| 0.083884                                     | 0.103459 | ERR      | ERR   | ERR   |            |               |      |          |  |
| 0.087146                                     | 0.104229 | ERR      | ERR   | ERR   |            |               |      |          |  |
| 0.088292                                     | 0.110459 | ERR      | ERR   | ERR   |            |               |      |          |  |
| 0.088988                                     | 0.108037 | ERR      | ERR   | ERR   |            |               |      |          |  |
| 0.090713                                     | 0.104433 | ERR      | ERR   | ERR   |            |               |      |          |  |
| 0.081086                                     | 0.081086 | ERR      | ERR   | ERR   |            |               |      |          |  |
| 0.080024                                     | 0.089994 | ERR      | ERR   | ERR   |            |               |      |          |  |
| 0.081542                                     | 0.094077 | ERR      | ERR   | ERR   |            |               |      |          |  |
| 0.081691                                     | 0.096137 | ERR      | ERR   | ERR   |            |               |      |          |  |
| 0.082882                                     | 0.09854  | ERR      | ERR   | ERR   |            |               |      |          |  |
| MEAN   | 0.089632 | 0.100403 | ERR   | ERR   |            |               |      |          |  |
| STD DEV                                      | 0.006617 | 0.00684  | ERR   | ERR   |            |               |      |          |  |

TABLE 6; ALLOY A6, LUBRICANT NO. 6

| STUD1    | STUD2    | STUD3    | STUD4 | STUD5 | MEAN<br>VALUE | STD<br>DEVIATION | TEST<br>FOR<br>MEAN | TEST<br>FOR<br>VARIANCE |
|----------|----------|----------|-------|-------|---------------|------------------|---------------------|-------------------------|
| 0.100864 | 0.111843 | ERR      | ERR   | ERR   |               |                  | t-TEST<br>t*=1.734  | F-TEST<br>F*=3.18       |
| 0.107075 | 0.114188 | ERR      | ERR   | ERR   | 0.110833      | 0.004473         |                     |                         |
| 0.113348 | 0.116238 | ERR      | ERR   | ERR   |               |                  |                     |                         |
| 0.110837 | 0.113635 | ERR      | ERR   | ERR   |               |                  |                     |                         |
| 0.108181 | 0.110323 | ERR      | ERR   | ERR   |               |                  |                     |                         |
| 0.089479 | 0.100664 | ERR      | ERR   | ERR   |               |                  |                     |                         |
| 0.094265 | 0.105652 | ERR      | ERR   | ERR   |               |                  |                     |                         |
| 0.100824 | 0.110459 | ERR      | ERR   | ERR   |               |                  |                     |                         |
| 0.101738 | 0.115035 | ERR      | ERR   | ERR   |               |                  |                     |                         |
| 0.104968 | 0.115142 | ERR      | ERR   | ERR   |               |                  |                     |                         |
| 0.089479 | 0.103459 | ERR      | ERR   | ERR   |               |                  |                     |                         |
| 0.095689 | 0.111343 | ERR      | ERR   | ERR   |               |                  |                     |                         |
| 0.097933 | 0.110459 | ERR      | ERR   | ERR   |               |                  |                     |                         |
| 0.098238 | 0.110137 | ERR      | ERR   | ERR   |               |                  |                     |                         |
| 0.10229  | 0.111394 | ERR      | ERR   | ERR   |               |                  |                     |                         |
| 0.083884 | 0.100664 | ERR      | ERR   | ERR   |               |                  |                     |                         |
| 0.094265 | 0.104229 | ERR      | ERR   | ERR   |               |                  |                     |                         |
| 0.097933 | 0.113348 | ERR      | ERR   | ERR   |               |                  |                     |                         |
| 0.097538 | 0.117133 | ERR      | ERR   | ERR   |               |                  |                     |                         |
| 0.104433 | 0.119424 | ERR      | ERR   | ERR   |               |                  |                     |                         |
| MEAN     | 0.099653 | 0.110738 | ERR   | ERR   |               |                  |                     |                         |
| STD DEV  | 0.007424 | 0.005324 | ERR   | ERR   |               |                  |                     |                         |

|                            |          |          |          |          |
|----------------------------|----------|----------|----------|----------|
| DESIGN VS RUN-IN           | t        | F        | Yes      | Yes      |
| DESIGN                     | 0.103823 | 0.008319 | 2.280067 | 3.458908 |
| USED STUD RUN-IN           | 0.103042 | 0.007688 |          |          |
| DESIGN VS USED STUD DESIGN | t        | F        | No       | No       |
| USED STUD DESIGN           | 0.103285 | 0.010985 | -0.12348 | 1.736985 |
| OVERALL                    |          |          |          |          |
|                            | 0.105196 | 0.008495 |          |          |

TABLE 7: ALLOY A, LUBRICANT NO. 7

| STUD1    | STUD2    | STUD3    | STUD4 | STUD5 | MEAN<br>VALUE | STD<br>DEVIATION     | TEST<br>FOR<br>MEAN | TEST<br>FOR<br>VARIANCE |
|----------|----------|----------|-------|-------|---------------|----------------------|---------------------|-------------------------|
| 0.134184 | 0.136975 | ERR      | ERR   | ERR   | RUN-IN        | 0.124958             | 0.009434            | t-TEST<br>t* = 1.734    |
| 0.131249 | 0.134092 | ERR      | ERR   | ERR   | XXXXXX        | XXXXXXXXXXXXXXXXXXXX | F-TEST<br>F* = 3.18 | 95% Confidence          |
| 0.125866 | 0.126828 | ERR      | ERR   | ERR   | DESIGN        | 0.11935              | 0.003855            | DESIGN VS RUN-IN<br>t   |
| 0.119232 | 0.117833 | ERR      | ERR   | ERR   | DESIGN        | 0.11935              | 0.003855            | F                       |
| 0.113536 | 0.109788 | ERR      | ERR   | ERR   | DESIGN        | 0.11935              | 0.003855            | Yes                     |
| 0.128601 | 0.123017 | ERR      | ERR   | ERR   | DESIGN        | 0.11935              | 0.003855            | Yes                     |
| 0.118454 | 0.119876 | ERR      | ERR   | ERR   | DESIGN        | 0.11935              | 0.003855            | Yes                     |
| 0.118164 | 0.118164 | ERR      | ERR   | ERR   | DESIGN        | 0.11935              | 0.003855            | Yes                     |
| 0.117833 | 0.116434 | ERR      | ERR   | ERR   | DESIGN        | 0.11935              | 0.003855            | Yes                     |
| 0.115142 | 0.117818 | ERR      | ERR   | ERR   | DESIGN        | 0.11935              | 0.003855            | Yes                     |
| 0.139766 | 0.128601 | ERR      | ERR   | ERR   | DESIGN        | 0.11935              | 0.003855            | Yes                     |
| 0.132671 | 0.126985 | ERR      | ERR   | ERR   | DESIGN        | 0.11935              | 0.003855            | Yes                     |
| 0.12394  | 0.128715 | ERR      | ERR   | ERR   | DESIGN        | 0.11935              | 0.003855            | Yes                     |
| 0.122029 | 0.126225 | ERR      | ERR   | ERR   | DESIGN        | 0.11935              | 0.003855            | Yes                     |
| 0.12103  | 0.12103  | ERR      | ERR   | ERR   | DESIGN        | 0.11935              | 0.003855            | Yes                     |
| 0.128601 | 0.123017 | ERR      | ERR   | ERR   | DESIGN        | 0.11935              | 0.003855            | Yes                     |
| 0.121298 | 0.118454 | ERR      | ERR   | ERR   | DESIGN        | 0.11935              | 0.003855            | Yes                     |
| 0.122978 | 0.118164 | ERR      | ERR   | ERR   | DESIGN        | 0.11935              | 0.003855            | Yes                     |
| 0.123428 | 0.115734 | ERR      | ERR   | ERR   | DESIGN        | 0.11935              | 0.003855            | Yes                     |
| 0.12424  | 0.118889 | ERR      | ERR   | ERR   | DESIGN        | 0.11935              | 0.003855            | Yes                     |
| MEAN     | 0.124112 | 0.122332 | ERR   | ERR   | DESIGN        | 0.11935              | 0.003855            | Yes                     |
| STD DEV  | 0.00673  | 0.006635 | ERR   | ERR   | DESIGN        | 0.11935              | 0.003855            | Yes                     |

TABLE 8; ALLOY A, LUBRICANT NO. 8

| STUD1    | STUD2    | STUD3    | STUD4 | STUD5 | MEAN<br>VALUE              | STD<br>DEVIATION     | TEST<br>FOR<br>MEAN | TEST<br>FOR<br>VARIANCE | t-TEST<br>F-TEST | 95% Confidence   |
|----------|----------|----------|-------|-------|----------------------------|----------------------|---------------------|-------------------------|------------------|------------------|
| 0.114637 | 0.089479 | ERR      | ERR   | ERR   | RUN-IN                     | 0.098523             | 0.006683            |                         | t*=1.734 F*=3.18 |                  |
| 0.095689 | 0.092842 | ERR      | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |                         |                  |                  |
| 0.096005 | 0.094077 | ERR      | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |                         |                  |                  |
| 0.096137 | 0.095437 | ERR      | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |                         |                  |                  |
| 0.095186 | 0.095745 | ERR      | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |                         |                  |                  |
| 0.099479 | 0.092276 | ERR      | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |                         |                  |                  |
| 0.094265 | 0.092842 | ERR      | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |                         |                  |                  |
| 0.096969 | 0.101788 | ERR      | ERR   | ERR   | DESIGN                     | 0.097136             | 0.005142            |                         | t                | DESIGN VS RUN-IN |
| 0.098238 | 0.103138 | ERR      | ERR   | ERR   | DESIGN                     | 0.097136             | 0.005142            |                         | F                |                  |
| 0.096863 | 0.105504 | ERR      | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |                         | No               | No               |
| 0.100664 | 0.095072 | ERR      | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |                         |                  |                  |
| 0.097112 | 0.101383 | ERR      | ERR   | ERR   | USED STUD RUN-IN           |                      |                     |                         |                  |                  |
| 0.098897 | 0.101788 | ERR      | ERR   | ERR   | 0.100453                   | 0.00395              |                     |                         |                  |                  |
| 0.097538 | 0.108037 | ERR      | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |                         |                  |                  |
| 0.09854  | 0.105504 | ERR      | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |                         |                  |                  |
| 0.095072 | 0.095072 | ERR      | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |                         |                  |                  |
| 0.095689 | 0.097112 | ERR      | ERR   | ERR   | DESIGN VS USED STUD DESIGN |                      |                     |                         |                  |                  |
| 0.101788 | 0.098897 | ERR      | ERR   | ERR   | USED STUD DESIGN           | 0.099898             | 0.004097            |                         | t                | F                |
| 0.103138 | 0.101738 | ERR      | ERR   | ERR   | USED STUD DESIGN           | 0.099898             | 0.004097            |                         | 1.328358         | 1.574854         |
| 0.103897 | 0.106575 | ERR      | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |                         | No               | No               |
| MEAN     | 0.09829  | 0.098715 | ERR   | ERR   | OVERALL                    | 0.098503             | 0.005181            |                         |                  |                  |
| STD DEV  | 0.005044 | 0.005436 | ERR   | ERR   |                            |                      |                     |                         |                  |                  |

TABLE 9; ALLOY A, LUBRICANT NO. 9

| STUD1    | STUD2    | STUD3 | STUD4 | STUD5 | MEAN<br>VALUE           | STD<br>DEVIATION | TEST<br>FOR<br>MEAN<br>t-TEST<br>t* = 1.734 | TEST<br>FOR<br>VARIANCE<br>F-TEST<br>F* = 3.18 | 95% Confidence |
|----------|----------|-------|-------|-------|-------------------------|------------------|---|--|----------------|
| 0.106254 | 0.109049 | ERR   | ERR   | ERR   | RUN-IN 0.122833         | 0.009415         | t-TEST<br>t* = 1.734                        | F-TEST<br>F* = 3.18                            | 95% Confidence |
| 0.118454 | 0.118454 | ERR   | ERR   | ERR   | XXXXXXXXXXXXXXXXXXXXXXX | XXXXXXXXXXXX     |   |  |                |
| 0.12394  | 0.124903 | ERR   | ERR   | ERR   | XXXXXXXXXXXXXXXXXXXXXXX | XXXXXXXXXXXX     |   |  |                |
| 0.131644 | 0.130974 | ERR   | ERR   | ERR   | XXXXXXXXXXXXXXXXXXXXXXX | XXXXXXXXXXXX     |   |  |                |
| 0.132114 | 0.130544 | ERR   | ERR   | ERR   | XXXXXXXXXXXXXXXXXXXXXXX | XXXXXXXXXXXX     |   |  |                |
| 0.106254 | 0.111843 | ERR   | ERR   | ERR   | XXXXXXXXXXXXXXXXXXXXXXX | XXXXXXXXXXXX     |   |  |                |
| 0.104229 | 0.112765 | ERR   | ERR   | ERR   | XXXXXXXXXXXXXXXXXXXXXXX | XXXXXXXXXXXX     |   |  |                |
| 0.098897 | 0.114312 | ERR   | ERR   | ERR   | XXXXXXXXXXXXXXXXXXXXXXX | XXXXXXXXXXXX     |   |  |                |
| 0.099638 | 0.112236 | ERR   | ERR   | ERR   | XXXXXXXXXXXXXXXXXXXXXXX | XXXXXXXXXXXX     |   |  |                |
| 0.097422 | 0.110859 | ERR   | ERR   | ERR   | XXXXXXXXXXXXXXXXXXXXXXX | XXXXXXXXXXXX     |   |  |                |
| 0.089479 | 0.103459 | ERR   | ERR   | ERR   | XXXXXXXXXXXXXXXXXXXXXXX | XXXXXXXXXXXX     |   |  |                |
| 0.082873 | 0.104229 | ERR   | ERR   | ERR   | XXXXXXXXXXXXXXXXXXXXXXX | XXXXXXXXXXXX     |   |  |                |
| 0.079612 | 0.100824 | ERR   | ERR   | ERR   | XXXXXXXXXXXXXXXXXXXXXXX | XXXXXXXXXXXX     |   |  |                |
| 0.075851 | 0.101038 | ERR   | ERR   | ERR   | XXXXXXXXXXXXXXXXXXXXXXX | XXXXXXXXXXXX     |   |  |                |
| 0.075608 | 0.101754 | ERR   | ERR   | ERR   | XXXXXXXXXXXXXXXXXXXXXXX | XXXXXXXXXXXX     |   |  |                |
| 0.083884 | 0.089479 | ERR   | ERR   | ERR   | XXXXXXXXXXXXXXXXXXXXXXX | XXXXXXXXXXXX     |   |  |                |
| 0.080024 | 0.091418 | ERR   | ERR   | ERR   | XXXXXXXXXXXXXXXXXXXXXXX | XXXXXXXXXXXX     |   |  |                |
| 0.077683 | 0.094077 | ERR   | ERR   | ERR   | XXXXXXXXXXXXXXXXXXXXXXX | XXXXXXXXXXXX     |   |  |                |
| 0.07366  | 0.097538 | ERR   | ERR   | ERR   | XXXXXXXXXXXXXXXXXXXXXXX | XXXXXXXXXXXX     |   |  |                |
| 0.070571 | 0.102826 | ERR   | ERR   | ERR   | XXXXXXXXXXXXXXXXXXXXXXX | XXXXXXXXXXXX     |   |  |                |
| MEAN     | 0.095405 | ERR   | ERR   | ERR   | OVERALL                 | 0.101767         |   |  |                |
| STD DEV  | 0.019658 | ERR   | ERR   | ERR   |                         | 0.01726          |   |  |                |

DESIGN VS RUN-IN  
t  
Yes No  
4.378945 2.144374

DESIGN VS USED STUD DESIGN  
t  
Yes No  
-5.26619 2.748152

TABLE 10; ALLOY A, LUBRICANT NO. 10

|         | STUD1    | STUD2    | STUD3 | STUD4 | STUD5 | MEAN<br>VALUE              | STD<br>DEVIATION     | TEST<br>FOR         |                    | 95% Confidence |
|---------|----------|----------|-------|-------|-------|----------------------------|----------------------|---------------------|--------------------|----------------|
|         |          |          |       |       |       |                            |                      | MEAN                | VARIANCE           |                |
|         | 0.097668 | 0.092276 | ERR   | ERR   | ERR   |                            |                      | t-TEST<br>t*=-1.734 | F-TEST<br>F*=-3.18 |                |
|         | 0.091418 | 0.089994 | ERR   | ERR   | ERR   | RUN-IN                     | 0.091591             | 0.003475            |                    |                |
|         | 0.094077 | 0.090221 | ERR   | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |                    |                |
|         | 0.093338 | 0.087529 | ERR   | ERR   | ERR   | DESIGN                     | 0.088193             | 0.003625            | 2.139811           | 1.088131       |
|         | 0.093508 | 0.085679 | ERR   | ERR   | ERR   | DESIGN VS RUN-IN           |                      |                     |                    |                |
|         | 0.089479 | 0.083884 | ERR   | ERR   | ERR   | t                          |                      |                     |                    |                |
|         | 0.091418 | 0.085722 | ERR   | ERR   | ERR   | Yes                        |                      |                     |                    |                |
|         | 0.094077 | 0.089257 | ERR   | ERR   | ERR   | No                         |                      |                     |                    |                |
|         | 0.091177 | 0.08388  | ERR   | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |                    |                |
|         | 0.089035 | 0.084001 | ERR   | ERR   | ERR   | USED STUD RUN-IN           |                      |                     |                    |                |
|         | 0.083884 | 0.083884 | ERR   | ERR   | ERR   | 0.0884                     | 0.003753             |                     |                    |                |
|         | 0.084297 | 0.089994 | ERR   | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |                    |                |
|         | 0.084435 | 0.093113 | ERR   | ERR   | ERR   | DESIGN VS USED STUD DESIGN |                      |                     |                    |                |
|         | 0.08315  | 0.090447 | ERR   | ERR   | ERR   | t                          |                      |                     |                    |                |
|         | 0.082322 | 0.088475 | ERR   | ERR   | ERR   | Yes                        |                      |                     |                    |                |
|         | 0.083884 | 0.081096 | ERR   | ERR   | ERR   | No                         |                      |                     |                    |                |
|         | 0.087146 | 0.082873 | ERR   | ERR   | ERR   | USED STUD DESIGN           |                      |                     |                    |                |
|         | 0.085399 | 0.087328 | ERR   | ERR   | ERR   | 0.084197                   | 0.002533             |                     |                    |                |
|         | 0.08388  | 0.08461  | ERR   | ERR   | ERR   | XXXXXX                     | XXXXXXXXXXXXXXXXXXXX |                     |                    |                |
|         | 0.079525 | 0.086238 | ERR   | ERR   | ERR   | OVERALL                    |                      |                     |                    |                |
| MEAN    | 0.088166 | 0.087025 | ERR   | ERR   | ERR   | 0.087595                   | 0.00425              |                     |                    |                |
| STD DEV | 0.005019 | 0.003347 | ERR   | ERR   | ERR   |                            |                      |                     |                    |                |

## **Appendix C**

### **COEFFICIENT OF FRICTION DATA FOR THE PHASE II TEST ASSEMBLIES**

This appendix includes the calculated coefficient of friction data, based on the equation of Appendix A. The actual test information, i.e, the individual loads and corresponding torque values, can be obtained by requesting from the authors at:

Westinghouse Electric Company  
Plant Apparatus Division  
500 Penn Center Boulevard  
Pittsburgh, PA 15235-5713

KEY TO APPENDIX C

| Alloy Code | Page Number | Alloy Combination              |                       |                            | Comments  |
|------------|-------------|--------------------------------|-----------------------|----------------------------|---|
|            |             | Stud                           | Nut                   | Washer                     |   |
| A          | App. B, 42  | AISI 4140                      | Carbon Steel, Gr 2H   | Carbon Steel               | Rolled threads                                      |
| AM         | 15, 33      | AISI 4140                      | Carbon Steel, Gr 2H   | Carbon Steel               | Machined threads                                    |
| P          | App. B      | AISI 4140, Mn Phosphate Coated | Carbon Steel, Gr 2H   | Carbon Steel               | Rolled threads                                      |
| AR1        | 13, 31      | AISI 4140                      | Carbon Steel, Gr 2H   | Carbon Steel               | 1.5 inches  |
| AZ         | 12, 30, 44  | Steel, Grade 5, Zinc plated    | Carbon Steel, Grade 5 | Carbon Steel               | Rolled threads                                      |
| AS         | 16, 34      | AISI 4340                      | AISI 4340             | Type 430 Stainless Nutlock | Machined threads 1.0 inches                         |
| M          | App. B      | K-500                          | Monel 400             | Carbon Steel               | Rolled threads                                      |
| MK         | 3, 21, 39   | K-500                          | K-500                 | Carbon Steel               | Rolled threads                                      |
| MCU        | 6, 24       | K-500                          | K-500                 | 70-30 Cu-Ni                | Rolled threads                                      |
| MH         | 7, 25       | K-500                          | K-500                 | HY 80                      | Rolled threads                                      |
| MS         | 4, 22       | K-500                          | K-500                 | Type 430                   | Rolled threads                                      |
| MI         | 5, 23       | K-500                          | K-500                 | Alloy 625                  | Rolled threads                                      |
| MA         | 14, 32      | K-500                          | Monel 400             | Carbon Steel               | Rolled threads 1.5 inches                           |
| I          | App. B, 40  | Alloy 625                      | Alloy 625             | Carbon Steel               | Rolled threads                                      |
| ICR        | 8, 26, 41   | Alloy 625, Chromium plated     | Alloy 625             | Carbon Steel               | Rolled threads                                      |
| II         | 9, 27       | Alloy 625                      | Alloy 625             | Alloy 625                  | Rolled threads                                      |
| IMC2       | 18, 35      | Alloy 625                      | Alloy 625             | Alloy 625                  | Military Specification Machined threads Class 2     |
| IMC3       | 17, 36      | Alloy 625                      | Alloy 625             | Alloy 625                  | Military Specification Machined threads Class 3     |
| IMA        | 19, 37      | Alloy 625                      | Alloy 625             | Alloy 625                  | Military Specification Machined threads 1.75 inches |
| IMB        | 20, 38      | Alloy 625                      | Alloy 625             | Alloy 625                  | Military Specification Machined threads 2.00 inches |
| T          | 11, 29, 43  | Titanium, Gr 5                 | Alloy 625             | Carbon Steel               | Rolled threads                                      |
| SS         | 10, 28      | Type 17-4PH Stainless Steel    | Type 316 stainless    | Type 316 stainless         | Rolled threads                                      |
| SSC        | 10, 28      | Type 17-4PH Stainless Steel    | Type 316 stainless    | Carbon Steel               | Rolled threads                                      |

### Lubricant Key

| Data Set Number  | Page Number   | Lubricant Used |
|--|---------------|----------------|
| 1 through 95   | 3 through 20  | Molykote P37   |
| 96 through 190   | 21 through 38 | RLGMO          |
| 191 through 220  | 39 through 44 | Fel Pro N7000  |
| Note: There were no Data Sets corresponding to Numbers 31 through 35 or 126 through 130. |               |                |

The main body of the following tables list each individual calculated coefficient of friction value, based on the equation of Appendix A, for every stud tested. The mean coefficient of friction and standard deviations for each individual stud is provided at the bottom of the table, while for alloy combinations that had at least four duplicate assemblies the mean coefficient of friction, standard deviation and the results of the statistical tests performed for all studs tested under the same loading sequence are provided to the right of the individual values.

#### Authors Note:

On the following pages, data columns which are marked as 'ERR' or '0.0000' signify that those assemblies were not tested. Markings of "ERR" or a blank entry within a column of data indicates that fewer than five load increments were used since higher loads would have exceeded the yield strength of at least one of the fastener assembly components, generally the washer or nut.

| SET 1-5 | Alloy Code MK | STUD1  | STUD2  | STUD3  | STUD4                | STUD5 | MEAN<br>VALUE | STD<br>DEVIATION | TEST for<br>Mean<br>95% Confidence<br>t*= 1.68 | TEST for<br>Variance<br>F*=1.98<br>= 0.505 | 90/95 Tolerance |
|---------|---------------|--------|--------|--------|----------------------|-------|---------------|------------------|--|--|-----------------|
| 0.1445  | 0.1283        | 0.1445 | 0.1413 | 0.1186 |                      |       |               |                  |  |  |                 |
| 0.1305  | 0.1223        | 0.1256 | 0.1191 | 0.1256 |                      |       |               |                  |  |  |                 |
| 0.1341  | 0.1242        | 0.1220 | 0.1165 | 0.1132 | RUN-IN               |       | 0.1246        | 0.0092           |  |  | 0.1474 0.1017   |
| 0.1266  | 0.1306        | 0.1185 | 0.1129 | 0.1137 |                      |       |               |                  |  |  |                 |
| 0.1229  | 0.1291        | 0.1166 | 0.1140 | 0.1185 | XXXXXXXXXXXXXXXXXXXX |       |               |                  |  |  |                 |
| 0.1121  | 0.1089        | 0.1218 | 0.1186 | 0.1121 |                      |       |               |                  |  |  |                 |
| 0.1028  | 0.1126        | 0.1256 | 0.1207 | 0.1256 |                      |       |               |                  |  |  |                 |
| 0.1121  | 0.1242        | 0.1165 | 0.1231 | 0.1176 | DESIGN               |       | 0.1184        | 0.0059           | 0.2046   | 2.4695                                     | 0.1329 0.1038   |
| 0.1145  | 0.1242        | 0.1193 | 0.1210 | 0.1226 |                      |       |               |                  | No   | Yes  |                 |
| 0.1160  | 0.1260        | 0.1179 | 0.1197 | 0.1235 | XXXXXXXXXXXXXXXXXXXX |       |               |                  |  |  |                 |
| 0.0894  | 0.1056        | 0.1089 | 0.1154 | 0.1089 |                      |       |               |                  |  |  |                 |
| 0.1012  | 0.1093        | 0.1110 | 0.1093 | 0.1028 |                      |       |               |                  |  |  |                 |
| 0.1033  | 0.1143        | 0.1110 | 0.1099 | 0.1099 | CYCLE3               |       | 0.1114        | 0.0079           | 0.2534   | 0.5617                                     | 0.1308 0.0920   |
| 0.1097  | 0.1234        | 0.1202 | 0.1089 | 0.1185 |                      |       |               |                  | No   | No   |                 |
| 0.1114  | 0.1254        | 0.1216 | 0.1160 | 0.1197 |                      |       |               |                  |  |  |                 |
| MEAN    | 0.1154        | 0.1206 | 0.1201 | 0.1178 |                      |       |               |                  |  |  |                 |
| STD DEV | 0.0143        | 0.0081 | 0.0084 | 0.0079 |                      |       |               |                  |  |  |                 |

| DATA SET 6,7 Alloy Code MS |        |       |     |       |     |                   |
|----------------------------|--------|-------|-----|-------|-----|-------------------|
| STUD1                      | STUD2  | STUD3 |     | STUD4 |     | STUD5             |
|                            |        |       |     |       |     |                   |
| 0.1380                     | 0.1380 |       | ERR | ERR   | ERR | ERR               |
| 0.1419                     | 0.1337 |       | ERR | ERR   | ERR | ERR               |
| 0.1462                     | 0.1275 |       | ERR | ERR   | ERR | ERR RUN-IN        |
| 0.1513                     | 0.1258 |       | ERR | ERR   | ERR | ERR               |
| 0.1660                     | 0.1372 |       | ERR | ERR   | ERR | ERR XXXXXXXXXXXXX |
|                            | 0.0959 |       | ERR | ERR   | ERR | ERR               |
|                            | 0.1044 |       | ERR | ERR   | ERR | ERR               |
|                            | 0.1143 |       | ERR | ERR   | ERR | ERR DESIGN        |
|                            | 0.1266 |       | ERR | ERR   | ERR | ERR               |
|                            | 0.1310 |       | ERR | ERR   | ERR | ERR XXXXXXXXXXXXX |
|                            | 0.1056 |       | ERR | ERR   | ERR | ERR               |
|                            | 0.0931 |       | ERR | ERR   | ERR | ERR               |
|                            | 0.1055 |       | ERR | ERR   | ERR | ERR CYCLE3        |
|                            | 0.1145 |       | ERR | ERR   | ERR | ERR               |
|                            | 0.1222 |       | ERR | ERR   | ERR | ERR               |
| Mean                       | 0.1238 |       | ERR | ERR   | ERR | ERR               |
| Std Dev                    | 0.0217 |       | ERR | ERR   | ERR | ERR               |

| DATA SET 11,12 Alloy Code MI |        |       |       |       |     |     |
|------------------------------|--------|-------|-------|-------|-----|-----|
| STUD1                        | STUD2  | STUD3 | STUD4 | STUD5 |     |     |
| 0.1413                       | 0.1348 | ERR   | ERR   | ERR   | ERR | ERR |
| 0.1305                       | 0.1402 | ERR   | ERR   | ERR   | ERR | ERR |
| 0.1363                       | 0.1610 | ERR   | ERR   | ERR   | ERR | ERR |
| ERR                          | ERR    | ERR   | ERR   | ERR   | ERR | ERR |
| ERR                          | ERR    | ERR   | ERR   | ERR   | ERR | ERR |
| 0.1121                       | 0.1056 | ERR   | ERR   | ERR   | ERR | ERR |
| 0.1110                       | 0.1093 | ERR   | ERR   | ERR   | ERR | ERR |
| 0.1220                       | 0.1286 | ERR   | ERR   | ERR   | ERR | ERR |
| ERR                          | ERR    | ERR   | ERR   | ERR   | ERR | ERR |
| ERR                          | ERR    | ERR   | ERR   | ERR   | ERR | ERR |
| 0.1121                       | 0.1024 | ERR   | ERR   | ERR   | ERR | ERR |
| 0.1093                       | 0.1028 | ERR   | ERR   | ERR   | ERR | ERR |
| 0.1176                       | 0.1154 | ERR   | ERR   | ERR   | ERR | ERR |
| ERR                          | ERR    | ERR   | ERR   | ERR   | ERR | ERR |
| ERR                          | ERR    | ERR   | ERR   | ERR   | ERR | ERR |
| 0.1214                       | 0.1222 | ERR   | ERR   | ERR   | ERR | ERR |
| 0.0119                       | 0.0203 | ERR   | ERR   | ERR   | ERR | ERR |
| Mean                         |        |       |       |       |     |     |
| Std Dev                      |        |       |       |       |     |     |



| DATA SET 21.22 Alloy Code MH |        |       |       |       |                          |     |
|------------------------------|--------|-------|-------|-------|--------------------------|-----|
| STUD1                        | STUD2  | STUD3 | STUD4 | STUD5 |                          |     |
| 0.1445                       | 0.1413 | ERR   | ERR   | ERR   | ERR                      | ERR |
| 0.1386                       | 0.1402 | ERR   | ERR   | ERR   | ERR                      | ERR |
| 0.1494                       | 0.1473 | ERR   | ERR   | ERR   | ERR RUN-IN               | ERR |
| 0.1529                       | 0.1498 | ERR   | ERR   | ERR   | ERR                      | ERR |
| 0.1569                       | 0.1539 | ERR   | ERR   | ERR   | ERR XXXXXXXXXXXXXXXXXXXX | ERR |
|                              | 0.1121 | ERR   | ERR   | ERR   | ERR                      | ERR |
|                              | 0.1175 | ERR   | ERR   | ERR   | ERR                      | ERR |
|                              | 0.1209 | ERR   | ERR   | ERR   | ERR DESIGN               | ERR |
|                              | 0.1234 | ERR   | ERR   | ERR   | ERR                      | ERR |
|                              | 0.1297 | ERR   | ERR   | ERR   | ERR XXXXXXXXXXXXXXXXXXXX | ERR |
|                              | 0.1121 | ERR   | ERR   | ERR   | ERR                      | ERR |
|                              | 0.1028 | ERR   | ERR   | ERR   | ERR                      | ERR |
|                              | 0.1110 | ERR   | ERR   | ERR   | ERR CYCLE3               | ERR |
|                              | 0.1226 | ERR   | ERR   | ERR   | ERR                      | ERR |
|                              | 0.1235 | ERR   | ERR   | ERR   | ERR                      | ERR |
| Mean                         | 0.1279 | ERR   | ERR   | ERR   | ERR                      | ERR |
| Std Dev                      | 0.0168 | ERR   | ERR   | ERR   | ERR                      | ERR |

| DATA SET 26-30 |        |        |        | Alloy Code ICR |                      | STUD5  | MEAN<br>VALUE | STD<br>DEVIATION | TEST for<br>Mean<br>95% Confidence<br>t*= 1.68 | TEST for<br>Variance<br>F*=1.98 | 90/95 Tolerance |
|----------------|--------|--------|--------|----------------|----------------------|--------|---------------|------------------|--|---------------------------------|-----------------|
| STUD1          | STUD2  | STUD3  | STUD4  |                |                      |        |               |                  |  |                                 |                 |
| 0.1276         | 0.1276 | 0.1034 | 0.1082 | 0.1034         |                      |        |               |                  |  |                                 |                 |
| 0.1083         | 0.1107 | 0.0889 | 0.0962 | 0.1011         |                      |        |               |                  |  |                                 |                 |
| 0.1119         | 0.1071 | 0.0876 | 0.0909 | 0.1006         | RUN-IN               | 0.1052 | 0.0106        |                  |  | 0.1313                          | 0.0791          |
| 0.1131         | 0.1070 | 0.0936 | 0.0948 | 0.1070         |                      |        |               |                  |  |                                 |                 |
| 0.1182         | 0.1112 | 0.1003 | 0.0973 | 0.1132         | XXXXXXXXXXXXXXXXXXXX |        |               |                  |  |                                 |                 |
| 0.1131         | 0.1034 | 0.0986 | 0.0937 | 0.1034         |                      |        |               | DESIGN vs RUN-IN |  |                                 |                 |
| 0.1083         | 0.0962 | 0.0889 | 0.0768 | 0.0962         |                      |        |               | t                | F  |                                 |                 |
| 0.1055         | 0.0925 | 0.0909 | 0.0763 | 0.0974         | DESIGN               | 0.0989 | 0.0114        | 0.1425           | 0.8505   | 0.1272                          | 0.0706          |
| 0.1119         | 0.0985 | 0.0972 | 0.0813 | 0.1034         |                      |        |               | No               | No   |                                 |                 |
| 0.1231         | 0.1053 | 0.1073 | 0.0894 | 0.1142         | XXXXXXXXXXXXXXXXXXXX |        |               |                  |  |                                 |                 |
| 0.1131         | 0.1179 | 0.1034 | 0.0840 | 0.1082         |                      |        |               |                  |  |                                 |                 |
| 0.1107         | 0.1035 | 0.0986 | 0.0720 | 0.0986         |                      |        |               |                  |  |                                 |                 |
| 0.0990         | 0.0974 | 0.1022 | 0.0714 | 0.1006         | CYCLE3               | 0.1014 | 0.0127        | -0.0510          | 0.8067   | 0.1329                          | 0.0699          |
| 0.1107         | 0.1046 | 0.1021 | 0.0826 | 0.1046         |                      |        |               | No               | No   |                                 |                 |
| 0.1211         | 0.1092 | 0.1142 | 0.0934 | 0.1112         |                      |        |               |                  |  |                                 |                 |
| Mean           | 0.1130 | 0.1061 | 0.0985 | 0.0872         | 0.1042               |        |               |                  |  |                                 |                 |
| Std Dev        | 0.0072 | 0.0088 | 0.0075 | 0.0105         | 0.0056               |        |               |                  |  |                                 |                 |

| DATA SET 36-40 | Alloy Code II |        |        |        | MEAN<br>VALUE | STD<br>DEVIATION     | TEST for<br>Mean<br>95% Confidence<br>t*= 1.68 | TEST for<br>Variance<br>F*=1.98 | 90/95 Tolerance |
|----------------|---------------|--------|--------|--------|---------------|----------------------|--|---------------------------------|-----------------|
|                | STUD2         |        | STUD3  |        |               |                      |  |                                 |                 |
|                | STUD1         | STUD2  | STUD3  | STUD4  |               |                      |  |                                 |                 |
|                | 0.1469        | 0.1373 | 0.1373 | 0.1276 | 0.1179        |                      |  |                                 |                 |
|                | 0.1519        | 0.1470 | 0.1374 | 0.1422 | 0.1325        |                      |  |                                 |                 |
|                | 0.1572        | 0.1556 | 0.1346 | 0.1556 | 0.1362        | RUN-IN               | 0.1492   |                                 | 0.1134          |
|                | 0.1632        | 0.1679 | 0.1498 | 0.1607 | 0.1449        |                      |  |                                 | 0.1850          |
|                | 0.1700        | 0.1756 | 0.1567 | 0.1681 | 0.1557        | XXXXXXXXXXXXXXXXXXXX |  |                                 |                 |
|                | 0.1131        | 0.1179 | 0.1373 | 0.1082 | 0.1179        |                      |  |                                 |                 |
|                | 0.1059        | 0.1035 | 0.1204 | 0.1083 | 0.1107        |                      |  |                                 |                 |
|                | 0.1087        | 0.1071 | 0.1330 | 0.1168 | 0.1071        | DESIGN               | 0.1156   | 0.0089                          | 0.1377          |
|                | 0.1119        | 0.1095 | 0.1144 | 0.1217 | 0.1107        |                      |  | No                              | Yes             |
|                | 0.1221        | 0.1191 | 0.1132 | 0.1348 | 0.1162        | XXXXXXXXXXXXXXXXXXXX |  |                                 |                 |
|                | 0.1082        | 0.1179 | 0.1082 | 0.1179 | 0.1082        |                      |  |                                 |                 |
|                | 0.0986        | 0.0962 | 0.1011 | 0.0986 | 0.0962        |                      |  |                                 |                 |
|                | 0.0974        | 0.1022 | 0.1071 | 0.1038 | 0.1006        | CYCLE3               | 0.1067   | 0.0072                          | 0.1244          |
|                | 0.1034        | 0.1021 | 0.1119 | 0.1119 | 0.1046        |                      |  | No                              | No              |
|                | 0.1152        | 0.1132 | 0.1132 | 0.1201 | 0.1092        |                      |  |                                 |                 |
| Mean           | 0.1249        | 0.1248 | 0.1250 | 0.1264 | 0.1179        |                      |  |                                 |                 |
| Std Dev        | 0.0253        | 0.0256 | 0.0169 | 0.0215 | 0.0170        |                      |  |                                 |                 |

| DATA SET 41-45 |        |        |        | Code SS |                      | Studs 41-44 only |       | MEAN<br>VALUE | STD<br>DEVIATION | TEST for          |          | 90/95 Tolerance |
|----------------|--------|--------|--------|---------|----------------------|------------------|-------|---------------|------------------|-------------------|----------|-----------------|
| STUD1          | STUD2  | STUD3  | STUD4  | STUD5   | STUD6                | STUD7            | STUD8 |               |                  | Mean              | Variance |                 |
| 0.1455         | 0.1455 | 0.1642 | 0.1525 | 0.1223  |                      |                  |       |               |                  |                   |          |                 |
| 0.1521         | 0.1603 | 0.1851 | 0.1603 | 0.1215  |                      |                  |       |               |                  |                   |          |                 |
| 0.1475         | 0.1638 | 0.1814 | 0.1711 | 0.1115  | RUN-IN               |                  |       | 0.1633        | 0.0150           |                   | F*=2.47  | 0.2040          |
| 0.1565         | 0.1674 | 0.1961 |        | 0.1034  |                      |                  |       |               |                  |                   |          | 0.1226          |
|                |        |        |        | 0.1006  | XXXXXXXXXXXXXXXXXXXX |                  |       |               |                  |                   |          |                 |
| 0.1432         | 0.1316 | 0.1269 | 0.0990 | 0.1153  |                      |                  |       |               |                  | DESIGN vs RUN-IN  |          |                 |
| 0.1262         | 0.1297 | 0.1227 | 0.1156 | 0.1180  |                      |                  |       |               |                  | t                 | F        |                 |
| 0.1208         | 0.1324 | 0.1339 | 0.1339 | 0.1123  | DESIGN               |                  |       | 0.1291        | 0.0122           | 0.6278            | 1.5004   | 0.1623          |
| 0.1313         | 0.1368 | 0.1527 |        | 0.1084  |                      |                  |       |               |                  | No                | No       | 0.0959          |
|                |        |        |        | 0.1067  | XXXXXXXXXXXXXXXXXXXX |                  |       |               |                  |                   |          |                 |
| 0.0990         | 0.1083 | 0.1083 | 0.0943 | 0.0990  |                      |                  |       |               |                  | DESIGN vs CYCLE 3 |          |                 |
| 0.0956         | 0.1074 | 0.1121 | 0.1074 | 0.1132  |                      |                  |       |               |                  | t                 | F        |                 |
| 0.1030         | 0.1169 | 0.1231 | 0.1300 | 0.1138  | CYCLE3               |                  |       | 0.1142        | 0.0145           | 0.2782            | 0.7147   | 0.1535          |
| 0.1179         | 0.1230 | 0.1379 | 0.1439 | 0.1062  |                      |                  |       |               |                  | No                | No       | 0.0750          |
|                |        |        |        | 0.1045  |                      |                  |       |               |                  |                   |          |                 |
| Mean           | 0.1282 | 0.1353 | 0.1454 | 0.1308  |                      |                  |       |               |                  |                   |          |                 |
| Std Dev        | 0.0564 | 0.0589 | 0.0658 | 0.0672  |                      |                  |       |               |                  |                   |          |                 |

| DATA SET 46-50 |        |        |        |        | Alloy Code T          |                  | 90/95 Tolerance                    |                            |
|----------------|--------|--------|--------|--------|-----------------------|------------------|------------------------------------|----------------------------|
| STUD1          | STUD2  | STUD3  | STUD4  | STUD5  | MEAN<br>VALUE         | STD<br>DEVIATION | TEST for<br>Mean<br>95% Confidence | TEST for<br>Variance<br>F* |
| 0.1039         | 0.1039 | 0.1112 | 0.1088 | 0.1015 |                       |                  | t*= 1.68                           | F*=1.98                    |
| 0.1124         | 0.1062 | 0.1148 | 0.1087 | 0.1087 |                       |                  |                                    |                            |
| 0.1184         | 0.1168 | 0.1160 | 0.1120 | 0.1160 | RUN-IN                | 0.1166           | 0.0092                             | = 0.505                    |
| 0.1273         | 0.1255 | 0.1185 | 0.1168 | 0.1215 |                       |                  |                                    |                            |
| 0.1324         | 0.1358 | 0.1253 | 0.1253 | 0.1267 | XXXXXXXXXXXXXXXXXXXXX |                  |                                    |                            |
| 0.1088         | 0.0893 | 0.0966 | 0.1088 | 0.0869 |                       |                  | DESIGN vs RUN-IN                   |                            |
| 0.1111         | 0.0952 | 0.0989 | 0.1209 | 0.0940 |                       |                  | t                                  | F                          |
| 0.1152         | 0.1012 | 0.1063 | 0.1256 | 0.1029 | DESIGN                | 0.1123           | 0.0142                             | 0.0908 0.4152              |
| 0.1168         | 0.1145 | 0.1168 | 0.1308 | 0.1180 |                       |                  | No                                 | Yes                        |
| 0.1329         | 0.1226 | 0.1338 | 0.1338 | 0.1267 | XXXXXXXXXXXXXXXXXXXXX |                  |                                    |                            |
| 0.1137         | 0.0966 | 0.1015 | 0.1088 | 0.0942 |                       |                  | DESIGN vs CYCLE 3                  |                            |
| 0.1185         | 0.0989 | 0.0927 | 0.1099 | 0.0964 |                       |                  | t                                  | F                          |
| 0.1232         | 0.1071 | 0.1021 | 0.1176 | 0.1087 | CYCLE3                | 0.1145           | 0.0146                             | 0.9397                     |
| 0.1279         | 0.1133 | 0.1156 | 0.1250 | 0.1145 |                       |                  | No                                 | No                         |
| 0.1387         | 0.1239 | 0.1474 | 0.1382 | 0.1285 |                       |                  |                                    | 0.1508                     |
|                |        |        |        |        |                       |                  |                                    | 0.0783                     |
| Mean           | 0.1201 | 0.1101 | 0.1132 | 0.1194 |                       |                  |                                    |                            |
| Std Dev        | 0.0100 | 0.0131 | 0.0147 | 0.0100 |                       |                  |                                    |                            |



| DATA SET 56-60 |        |        |        |        | Alloy Code AR1       |                  | 90/95 Tolerance                    |                                 |
|----------------|--------|--------|--------|--------|----------------------|------------------|------------------------------------|---------------------------------|
| STUD1          | STUD2  | STUD3  | STUD4  | STUD5  | MEAN<br>VALUE        | STD<br>DEVIATION | TEST for<br>Mean<br>95% Confidence | TEST for<br>Variance<br>F*=1.98 |
| 0.1195         | 0.1289 | 0.1195 | 0.0934 | 0.1108 |                      |                  | t*= 1.68                           | F*=0.505                        |
| 0.1243         | 0.1180 | 0.1095 | 0.0905 | 0.1117 |                      |                  |                                    |                                 |
| 0.1206         | 0.1132 | 0.0987 | 0.0987 | 0.1073 | RUN-IN               | 0.1106           | 0.0099                             |                                 |
| 0.1199         | 0.1144 | 0.1045 | 0.0979 | 0.1056 |                      |                  |                                    | 0.1352                          |
| 0.1186         | 0.1195 | 0.1072 | 0.1037 | 0.1090 | XXXXXXXXXXXXXXXXXXXX |                  |                                    | 0.0860                          |
| 0.1195         | 0.1289 | 0.1242 | 0.0934 | 0.1289 |                      |                  | DESIGN vs RUN-IN                   |                                 |
| 0.1222         | 0.1272 | 0.1159 | 0.1117 | 0.1222 |                      |                  | t                                  | F                               |
| 0.1251         | 0.1251 | 0.1221 | 0.1103 | 0.1177 | DESIGN               | 0.1211           | 0.0077                             | -0.2978                         |
| 0.1254         | 0.1243 | 0.1199 | 0.1199 | 0.1265 |                      |                  | No                                 | No                              |
| 0.1291         | 0.1274 | 0.1169 | 0.1186 | 0.1256 | XXXXXXXXXXXXXXXXXXXX |                  |                                    |                                 |
| 0.1152         | 0.1382 | 0.1195 | 0.0804 | 0.1242 |                      |                  | DESIGN vs CYCLE 3                  |                                 |
| 0.1159         | 0.1488 | 0.1138 | 0.1026 | 0.1272 |                      |                  | t                                  | F                               |
| 0.1221         | 0.1398 | 0.1118 | 0.1118 | 0.1206 | CYCLE3               | 0.1214           | 0.0138                             | -0.0074                         |
| 0.1166         | 0.1342 | 0.1177 | 0.1177 | 0.1254 |                      |                  | No                                 | Yes                             |
| 0.1230         | 0.1414 | 0.1186 | 0.1169 | 0.1326 |                      |                  |                                    |                                 |
| Mean           | 0.1212 | 0.1286 | 0.1147 | 0.1197 |                      |                  |                                    |                                 |
| Std Dev        | 0.0039 | 0.0103 | 0.0071 | 0.0087 |                      |                  |                                    |                                 |

90/95 Tolerance

MEAN VALUE

Alloy Code MA

DATA SET 61-65

| STUD1  | STUD2  | STUD3  | STUD4  | STUD5  | TEST for<br>Mean | TEST for<br>Variance | 90/95 Tolerance |
|--------|--------|--------|--------|--------|------------------|----------------------|-----------------|
| 0.1253 | 0.1354 | 0.1404 | 0.1458 | 0.1253 |                  |                      |                 |
| 0.1230 | 0.1259 | 0.1412 | 0.1337 | 0.1312 |                  |                      |                 |
| 0.1265 | 0.1195 | 0.1369 | 0.1352 | 0.1456 |                  |                      |                 |
| 0.1351 | 0.1273 | 0.1454 | 0.1454 | 0.1570 |                  |                      |                 |
| 0.1524 | 0.1391 | 0.1658 | 0.1617 | 0.1761 |                  |                      |                 |
| 0.1253 | 0.1051 | 0.1253 | 0.1203 | 0.1203 |                  |                      |                 |
| 0.1145 | 0.1173 | 0.1230 | 0.1173 | 0.1116 |                  |                      |                 |
| 0.1137 | 0.1152 | 0.1213 | 0.1213 | 0.1079 |                  |                      |                 |
| 0.1221 | 0.1208 | 0.1234 | 0.1299 | 0.1273 |                  |                      |                 |
| 0.1309 | 0.1370 | 0.1268 | 0.1494 | 0.1391 |                  |                      |                 |
| 0.1152 | 0.1051 | 0.1253 | 0.1203 | 0.1152 |                  |                      |                 |
| 0.1063 | 0.1013 | 0.1173 | 0.1230 | 0.1063 |                  |                      |                 |
| 0.1021 | 0.1065 | 0.1213 | 0.1166 | 0.1123 |                  |                      |                 |
| 0.1183 | 0.1118 | 0.1196 | 0.1247 | 0.1183 |                  |                      |                 |
| 0.1247 | 0.1257 | 0.1227 | 0.1432 | 0.1268 |                  |                      |                 |

Mean  
Std Dev

|        |        |        |        |        |
|--------|--------|--------|--------|--------|
| 0.1224 | 0.1195 | 0.1304 | 0.1325 | 0.1280 |
| 0.0121 | 0.0122 | 0.0131 | 0.0138 | 0.0195 |

90/95 Tolerance

MEAN VALUE

Alloy Code MA

DATA SET 61-65

| STUD1  | STUD2  | STUD3  | STUD4  | STUD5  | TEST for<br>Mean | TEST for<br>Variance | 90/95 Tolerance |
|--------|--------|--------|--------|--------|------------------|----------------------|-----------------|
| 0.1253 | 0.1354 | 0.1404 | 0.1458 | 0.1253 |                  |                      |                 |
| 0.1230 | 0.1259 | 0.1412 | 0.1337 | 0.1312 |                  |                      |                 |
| 0.1265 | 0.1195 | 0.1369 | 0.1352 | 0.1456 |                  |                      |                 |
| 0.1351 | 0.1273 | 0.1454 | 0.1454 | 0.1570 |                  |                      |                 |
| 0.1253 | 0.1051 | 0.1253 | 0.1203 | 0.1203 |                  |                      |                 |
| 0.1145 | 0.1173 | 0.1230 | 0.1173 | 0.1116 |                  |                      |                 |
| 0.1137 | 0.1152 | 0.1213 | 0.1213 | 0.1079 |                  |                      |                 |
| 0.1221 | 0.1208 | 0.1234 | 0.1299 | 0.1273 |                  |                      |                 |
| 0.1152 | 0.1051 | 0.1253 | 0.1203 | 0.1152 |                  |                      |                 |
| 0.1063 | 0.1013 | 0.1173 | 0.1230 | 0.1063 |                  |                      |                 |
| 0.1021 | 0.1065 | 0.1213 | 0.1166 | 0.1123 |                  |                      |                 |
| 0.1183 | 0.1118 | 0.1196 | 0.1247 | 0.1183 |                  |                      |                 |

Mean  
Std Dev

|        |        |        |        |        |
|--------|--------|--------|--------|--------|
| 0.1190 | 0.1159 | 0.1284 | 0.1278 | 0.1232 |
| 0.0092 | 0.0105 | 0.0097 | 0.0102 | 0.0154 |

\* Excludes the highest torque increment, see discussion under the Monel K-500 section of Phase II Test Results.

| DATA SET 66-70 |        |        |        |        | Alloy Code AM |       | MEAN<br>VALUE        | STD<br>DEVIATION | TEST for          |            | 90/95 Tolerance |
|----------------|--------|--------|--------|--------|---------------|-------|----------------------|------------------|-------------------|------------|-----------------|
| STUD1          | STUD2  | STUD3  | STUD4  | STUD5  | STUD3         | STUD4 |                      |                  | Mean              | Variance   |                 |
| 0.0905         | 0.0933 | 0.0988 | 0.0960 | 0.0738 |               |       |                      |                  |                   |            |                 |
| 0.0965         | 0.1063 | 0.1021 | 0.1035 | 0.0854 |               |       |                      |                  | $t^*=1.68$        | $F^*=1.98$ |                 |
| 0.1057         | 0.1047 | 0.1094 | 0.1132 | 0.0867 |               |       | 0.0987               | 0.0095           |                   | = 0.505    | 0.1222          |
| 0.0990         | 0.1060 | 0.1011 | 0.1108 | 0.0849 |               |       |                      |                  |                   |            | 0.0752          |
| 0.1029         | 0.1013 | 0.1013 | 0.1066 | 0.0876 |               |       | XXXXXXXXXXXXXXXXXXXX |                  |                   |            |                 |
| 0.0960         | 0.0933 | 0.0933 | 0.0905 | 0.0905 |               |       |                      |                  | DESIGN vs RUN-IN  |            |                 |
| 0.1063         | 0.0924 | 0.1035 | 0.0965 | 0.0965 |               |       |                      |                  | $t$               | F          |                 |
| 0.1085         | 0.1057 | 0.1123 | 0.1085 | 0.0952 |               |       | DESIGN               | 0.1028           | -0.1156           | 1.3622     | 0.1229          |
| 0.1101         | 0.1108 | 0.1094 | 0.1087 | 0.0956 |               |       |                      |                  | No                | Yes        | 0.0826          |
| 0.1120         | 0.1120 | 0.1130 | 0.1120 | 0.0970 |               |       | XXXXXXXXXXXXXXXXXXXX |                  |                   |            |                 |
| 0.0933         | 0.0905 | 0.0849 | 0.0877 | 0.0905 |               |       |                      |                  | DESIGN vs CYCLE 3 |            |                 |
| 0.1063         | 0.0993 | 0.0965 | 0.0938 | 0.0910 |               |       |                      |                  | $t$               | F          |                 |
| 0.1057         | 0.1132 | 0.1057 | 0.1142 | 0.1009 |               |       | CYCLE3               | 0.1027           | 0.0035            | 0.7070     | 0.1266          |
| 0.1108         | 0.1143 | 0.1046 | 0.1129 | 0.0997 |               |       |                      |                  | No                | No         | 0.0787          |
| 0.1146         | 0.1136 | 0.1093 | 0.1146 | 0.0986 |               |       |                      |                  |                   |            |                 |
| Mean           | 0.1039 | 0.1038 | 0.0993 | 0.1046 |               |       |                      |                  |                   |            |                 |
| Std Dev        | 0.0073 | 0.0084 | 0.0169 | 0.0093 |               |       |                      |                  |                   |            |                 |



| DATA SET 76-80 |        |        |        |                      | Alloy Code IMC3       |          | MEAN<br>VALUE | STD<br>DEVIATION | TEST for | TEST for | 90/95 Tolerance |
|----------------|--------|--------|--------|----------------------|-----------------------|----------|---------------|------------------|----------|----------|-----------------|
| STUD1          | STUD2  | STUD3  | STUD4  | STUD5                | Mean                  | Variance |               |                  |          |          |                 |
|                |        |        |        |                      | 95% Confidence        |          |               |                  |          |          |                 |
|                |        |        |        |                      | t*= 1.68      F*=1.98 |          |               |                  |          |          |                 |
| 0.1082         | 0.1034 | 0.1082 | 0.1034 | 0.0986               | 0.1008                | 0.0076   | 0.1197        | 0.0820           |          |          |                 |
| 0.0962         | 0.0986 | 0.0962 | 0.0962 | 0.0841               |                       |          |               |                  |          |          |                 |
| 0.0990         | 0.0974 | 0.0974 | 0.1022 | 0.0860               |                       |          |               |                  |          |          |                 |
| 0.0985         | 0.1070 | 0.1021 | 0.1021 | 0.0936               |                       |          |               |                  |          |          |                 |
| 0.1053         | 0.1182 | 0.1132 | 0.1092 | 0.0964               |                       |          |               |                  |          |          |                 |
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| DATA SET 81-85 |        |            |        |        |        |        |        |        |           | 90/95 Tolerance  |
|----------------|--------|------------|--------|--------|--------|--------|--------|--------|-----------|------------------|
|                |        | Alloy Code |        | IMC2   |        | STUD5  |        | MEAN   | STD       |                  |
| STUD1          | STUD2  | STUD3      | STUD4  | STUD5  | STUD6  | STUD7  | STUD8  | VALUE  | DEVIATION | TEST for         |
| 0.1179         | 0.1228 | 0.1179     | 0.1324 | 0.1373 | 0.1373 | 0.1373 | 0.1373 | 0.1109 | 0.0098    | TEST for         |
| 0.1107         | 0.1035 | 0.0986     | 0.1011 | 0.1107 | 0.1107 | 0.1107 | 0.1107 | 0.1109 | 0.0098    | 95% Confidence   |
| 0.1103         | 0.0974 | 0.0990     | 0.1038 | 0.1095 | 0.1095 | 0.1095 | 0.1095 | 0.1109 | 0.0098    | t*= 1.68 F*=1.98 |
| 0.1119         | 0.1070 | 0.1009     | 0.1095 | 0.1095 | 0.1095 | 0.1095 | 0.1095 | 0.1109 | 0.0098    | = 0.505          |
| 0.1201         | 0.1082 | 0.1063     | 0.1112 | 0.1132 | 0.1132 | 0.1132 | 0.1132 | 0.1109 | 0.0098    |                  |
| 0.0840         | 0.0986 | 0.0937     | 0.0986 | 0.0889 | 0.0889 | 0.0889 | 0.0889 | 0.1109 | 0.0098    |                  |
| 0.0744         | 0.0792 | 0.0841     | 0.0865 | 0.0841 | 0.0841 | 0.0841 | 0.0841 | 0.1109 | 0.0098    |                  |
| 0.0860         | 0.0828 | 0.0876     | 0.0941 | 0.0909 | 0.0909 | 0.0909 | 0.0909 | 0.1109 | 0.0098    |                  |
| 0.0838         | 0.0924 | 0.0972     | 0.0960 | 0.0972 | 0.0972 | 0.0972 | 0.0972 | 0.1109 | 0.0098    |                  |
| 0.0934         | 0.0993 | 0.0983     | 0.1053 | 0.1023 | 0.1023 | 0.1023 | 0.1023 | 0.1109 | 0.0098    |                  |
| 0.0695         | 0.0840 | 0.0840     | 0.0986 | 0.0889 | 0.0889 | 0.0889 | 0.0889 | 0.1109 | 0.0098    |                  |
| 0.0647         | 0.0720 | 0.0768     | 0.0841 | 0.0841 | 0.0841 | 0.0841 | 0.0841 | 0.1109 | 0.0098    |                  |
| 0.0698         | 0.0795 | 0.0828     | 0.0925 | 0.0925 | 0.0925 | 0.0925 | 0.0925 | 0.1109 | 0.0098    |                  |
| 0.0801         | 0.0911 | 0.0924     | 0.1009 | 0.0997 | 0.0997 | 0.0997 | 0.0997 | 0.1109 | 0.0098    |                  |
| 0.0874         | 0.0983 | 0.0964     | 0.1043 | 0.1063 | 0.1063 | 0.1063 | 0.1063 | 0.1109 | 0.0098    |                  |
| Mean           | 0.0909 | 0.0944     | 0.1013 | 0.1011 | 0.1011 | 0.1011 | 0.1011 | 0.1109 | 0.0098    |                  |
| Std Dev        | 0.0187 | 0.0134     | 0.0104 | 0.0115 | 0.0142 | 0.0142 | 0.0142 | 0.1109 | 0.0098    |                  |

| DATA SET 81-85 |        |            |        |        |        |        |        |        |           | 90/95 Tolerance  |
|----------------|--------|------------|--------|--------|--------|--------|--------|--------|-----------|------------------|
|                |        | Alloy Code |        | IMC2   |        | STUD5  |        | MEAN   | STD       |                  |
| STUD1          | STUD2  | STUD3      | STUD4  | STUD5  | STUD6  | STUD7  | STUD8  | VALUE  | DEVIATION | TEST for         |
| 0.1179         | 0.1228 | 0.1179     | 0.1324 | 0.1373 | 0.1373 | 0.1373 | 0.1373 | 0.1109 | 0.0098    | TEST for         |
| 0.1107         | 0.1035 | 0.0986     | 0.1011 | 0.1107 | 0.1107 | 0.1107 | 0.1107 | 0.1109 | 0.0098    | 95% Confidence   |
| 0.1103         | 0.0974 | 0.0990     | 0.1038 | 0.1095 | 0.1095 | 0.1095 | 0.1095 | 0.1109 | 0.0098    | t*= 1.68 F*=1.98 |
| 0.1119         | 0.1070 | 0.1009     | 0.1095 | 0.1095 | 0.1095 | 0.1095 | 0.1095 | 0.1109 | 0.0098    | = 0.505          |
| 0.1201         | 0.1082 | 0.1063     | 0.1112 | 0.1132 | 0.1132 | 0.1132 | 0.1132 | 0.1109 | 0.0098    |                  |
| 0.0840         | 0.0986 | 0.0937     | 0.0986 | 0.0889 | 0.0889 | 0.0889 | 0.0889 | 0.1109 | 0.0098    |                  |
| 0.0744         | 0.0792 | 0.0841     | 0.0865 | 0.0841 | 0.0841 | 0.0841 | 0.0841 | 0.1109 | 0.0098    |                  |
| 0.0860         | 0.0828 | 0.0876     | 0.0941 | 0.0909 | 0.0909 | 0.0909 | 0.0909 | 0.1109 | 0.0098    |                  |
| 0.0838         | 0.0924 | 0.0972     | 0.0960 | 0.0972 | 0.0972 | 0.0972 | 0.0972 | 0.1109 | 0.0098    |                  |
| 0.0934         | 0.0993 | 0.0983     | 0.1053 | 0.1023 | 0.1023 | 0.1023 | 0.1023 | 0.1109 | 0.0098    |                  |
| 0.0695         | 0.0840 | 0.0840     | 0.0986 | 0.0889 | 0.0889 | 0.0889 | 0.0889 | 0.1109 | 0.0098    |                  |
| 0.0647         | 0.0720 | 0.0768     | 0.0841 | 0.0841 | 0.0841 | 0.0841 | 0.0841 | 0.1109 | 0.0098    |                  |
| 0.0698         | 0.0795 | 0.0828     | 0.0925 | 0.0925 | 0.0925 | 0.0925 | 0.0925 | 0.1109 | 0.0098    |                  |
| 0.0801         | 0.0911 | 0.0924     | 0.1009 | 0.0997 | 0.0997 | 0.0997 | 0.0997 | 0.1109 | 0.0098    |                  |
| 0.0874         | 0.0983 | 0.0964     | 0.1043 | 0.1063 | 0.1063 | 0.1063 | 0.1063 | 0.1109 | 0.0098    |                  |
| Mean           | 0.0909 | 0.0944     | 0.1013 | 0.1011 | 0.1011 | 0.1011 | 0.1011 | 0.1109 | 0.0098    |                  |
| Std Dev        | 0.0187 | 0.0134     | 0.0104 | 0.0115 | 0.0142 | 0.0142 | 0.0142 | 0.1109 | 0.0098    |                  |

## 90/95 Tolerance



[illegible]

| DATA SET 101, 102 |        | Alloy Code MS |        |        |            |
|-------------------|--------|---------------|--------|--------|------------|
| STUD1             | STUD2  | STUD3         | STUD4  | STUD5  |            |
| 0.1121            | 0.1186 | 0.0000        | 0.0000 | 0.0000 |            |
| 0.1175            | 0.1110 | 0.0000        | 0.0000 | 0.0000 |            |
| 0.1275            | 0.1187 | 0.0000        | 0.0000 | 0.0000 | RUN-IN     |
| 0.1330            | 0.1242 | 0.0000        | 0.0000 | 0.0000 |            |
| 0.1397            | 0.1335 | 0.0000        | 0.0000 | 0.0000 | XXXXXXXXXX |
| 0.0862            | 0.0829 | 0.0000        | 0.0000 | 0.0000 |            |
| 0.0979            | 0.0947 | 0.0000        | 0.0000 | 0.0000 |            |
| 0.1033            | 0.0934 | 0.0000        | 0.0000 | 0.0000 | DESIGN     |
| 0.1081            | 0.1014 | 0.0000        | 0.0000 | 0.0000 |            |
| 0.1088            | 0.1049 | 0.0000        | 0.0000 | 0.0000 | XXXXXXXXXX |
| 0.0894            | 0.0862 | 0.0000        | 0.0000 | 0.0000 |            |
| 0.0947            | 0.0963 | 0.0000        | 0.0000 | 0.0000 |            |
| 0.0956            | 0.0978 | 0.0000        | 0.0000 | 0.0000 | CYCLE3     |
| 0.0989            | 0.0997 | 0.0000        | 0.0000 | 0.0000 |            |
| 0.1023            | 0.1023 | 0.0000        | 0.0000 | 0.0000 |            |
| Mean              | 0.1077 | 0.1044        | 0.0000 | 0.0000 |            |
| Std Dev           | 0.0158 | 0.0142        | 0.0000 | 0.0000 |            |

| DATA SET 106,107 Alloy Code MI |        |       |       |       |                   |
|--------------------------------|--------|-------|-------|-------|-------------------|
| STUD1                          | STUD2  | STUD3 | STUD4 | STUD5 |                   |
| 0.1186                         | 0.1186 | ERR   | ERR   | ERR   | ERR               |
| 0.1175                         | 0.1158 | ERR   | ERR   | ERR   | ERR               |
| 0.1308                         | 0.1319 | ERR   | ERR   | ERR   | ERR RUN-IN        |
| ERR                            | ERR    | ERR   | ERR   | ERR   | ERR               |
| ERR                            | ERR    | ERR   | ERR   | ERR   | ERR XXXXXXXXXXXXX |
| 0.1154                         | 0.1121 | ERR   | ERR   | ERR   | ERR               |
| 0.1093                         | 0.1093 | ERR   | ERR   | ERR   | ERR               |
| 0.1220                         | 0.1231 | ERR   | ERR   | ERR   | ERR DESIGN        |
| ERR                            | ERR    | ERR   | ERR   | ERR   | ERR               |
| ERR                            | ERR    | ERR   | ERR   | ERR   | ERR XXXXXXXXXXXXX |
| 0.0927                         | 0.1218 | ERR   | ERR   | ERR   | ERR               |
| 0.0947                         | 0.1126 | ERR   | ERR   | ERR   | ERR               |
| 0.1099                         | 0.1220 | ERR   | ERR   | ERR   | ERR CYCLE3        |
| ERR                            | ERR    | ERR   | ERR   | ERR   | ERR               |
| ERR                            | ERR    | ERR   | ERR   | ERR   | ERR               |
| 0.1123                         | 0.1186 | ERR   | ERR   | ERR   | ERR               |
| 0.0124                         | 0.0070 | ERR   | ERR   | ERR   | ERR               |
| Mean                           |        |       |       |       |                   |
| Std Dev                        |        |       |       |       |                   |

|         | STUD1  | STUD2  | STUD3 | STUD4 | STUD5 |                              |
|---------|--------|--------|-------|-------|-------|------------------------------|
|         | 0.1347 | 0.1403 |       | ERR   | ERR   | ERR                          |
|         | 0.1154 | 0.1186 |       | ERR   | ERR   | ERR                          |
|         | 0.1167 | 0.1231 |       | ERR   | ERR   | ERR RUN-IN                   |
|         | 0.1175 | 0.1288 |       | ERR   | ERR   | ERR                          |
|         | 0.1232 | 0.1375 |       | ERR   | ERR   | ERR XXXXXXXXXXXXXXXXXXXXXXXX |
|         | 0.1065 | 0.1234 |       | ERR   | ERR   | ERR                          |
|         | 0.0894 | 0.1056 |       | ERR   | ERR   | ERR                          |
|         | 0.0820 | 0.1058 |       | ERR   | ERR   | ERR DESIGN                   |
|         | 0.0865 | 0.1093 |       | ERR   | ERR   | ERR                          |
|         | 0.0932 | 0.1153 |       | ERR   | ERR   | ERR XXXXXXXXXXXXXXXXXXXXXXXX |
|         | 0.0895 | 0.1178 |       | ERR   | ERR   | ERR                          |
|         | 0.0959 | 0.1024 |       | ERR   | ERR   | ERR                          |
|         | 0.0907 | 0.0972 |       | ERR   | ERR   | ERR CYCLE3                   |
|         | 0.0914 | 0.1028 |       | ERR   | ERR   | ERR                          |
|         | 0.0906 | 0.1036 |       | ERR   | ERR   | ERR                          |
| Mean    | 0.1015 | 0.1154 |       | ERR   | ERR   | ERR                          |
| Std Dev | 0.0160 | 0.0132 |       | ERR   | ERR   | ERR                          |

DATA SET 116, 117 Alloy Code MH

| STUD1   | STUD2  | STUD3 | STUD4 | STUD5 |                              |
|---------|--------|-------|-------|-------|------------------------------|
| 0.1478  | 0.1348 | ERR   | ERR   | ERR   | ERR                          |
| 0.1337  | 0.1337 | ERR   | ERR   | ERR   | ERR                          |
| 0.1385  | 0.1440 | ERR   | ERR   | ERR   | ERR RUN-IN                   |
| 0.1338  | 0.1451 | ERR   | ERR   | ERR   | ERR                          |
| 0.1310  | 0.1496 | ERR   | ERR   | ERR   | ERR XXXXXXXXXXXXXXXXXXXXXXXX |
|         | 0.1024 | ERR   | ERR   | ERR   | ERR                          |
|         | 0.0931 | ERR   | ERR   | ERR   | ERR                          |
|         | 0.0989 | ERR   | ERR   | ERR   | ERR DESIGN                   |
|         | 0.1039 | ERR   | ERR   | ERR   | ERR                          |
|         | 0.1114 | ERR   | ERR   | ERR   | ERR XXXXXXXXXXXXXXXXXXXXXXXX |
|         | 0.0862 | ERR   | ERR   | ERR   | ERR                          |
|         | 0.0865 | ERR   | ERR   | ERR   | ERR                          |
|         | 0.0945 | ERR   | ERR   | ERR   | ERR CYCLE3                   |
|         | 0.1056 | ERR   | ERR   | ERR   | ERR                          |
|         | 0.1095 | ERR   | ERR   | ERR   | ERR                          |
| Mean    | 0.1118 | ERR   | ERR   | ERR   | ERR                          |
| Std Dev | 0.0201 | ERR   | ERR   | ERR   | ERR                          |

| DATA SET 121-125 |        |        |        |        | Alloy Code ICR |        | STUD5  | MEAN<br>VALUE        | STD<br>DEVIATION | TEST for |          | 90/95 Tolerance |
|------------------|--------|--------|--------|--------|----------------|--------|--------|----------------------|------------------|----------|----------|-----------------|
| STUD1            | STUD2  | STUD3  | STUD4  | STUD5  | STUD3          | STUD4  |        |                      |                  | Mean     | Variance |                 |
| 0.1131           | 0.1034 | 0.1131 | 0.0986 | 0.1034 | 0.1131         | 0.0986 | 0.1034 | 0.1043               | 0.0066           | t*= 1.68 | F*=1.98  | 0.1206          |
| 0.1059           | 0.1035 | 0.1011 | 0.0865 | 0.1035 | 0.1011         | 0.0865 | 0.1035 |                      |                  |          | = 0.505  | 0.0881          |
| 0.1087           | 0.1022 | 0.1022 | 0.0925 | 0.1038 | 0.1022         | 0.0925 | 0.1038 |                      |                  |          |          |                 |
| 0.1119           | 0.1046 | 0.1034 | 0.0972 | 0.1034 | 0.1034         | 0.0972 | 0.1034 |                      |                  |          |          |                 |
| 0.1182           | 0.1073 | 0.1092 | 0.1033 | 0.1082 | 0.1092         | 0.1033 | 0.1082 | XXXXXXXXXXXXXXXXXXXX |                  |          |          |                 |
| 0.1131           | 0.1034 | 0.0792 | 0.0937 | 0.1131 | 0.0792         | 0.0937 | 0.1131 |                      |                  |          |          |                 |
| 0.1107           | 0.0986 | 0.0744 | 0.0720 | 0.0914 | 0.0744         | 0.0720 | 0.0914 |                      |                  |          |          |                 |
| 0.1200           | 0.0957 | 0.0763 | 0.0714 | 0.0925 | 0.0763         | 0.0714 | 0.0925 | DESIGN               | 0.0165           | 0.2067   | 0.1597   | 0.1355          |
| 0.1229           | 0.0985 | 0.0813 | 0.0728 | 0.0924 | 0.0813         | 0.0728 | 0.0924 |                      |                  | No       | Yes      | 0.0541          |
| 0.1251           | 0.1023 | 0.0934 | 0.0775 | 0.0983 | 0.0934         | 0.0775 | 0.0983 | XXXXXXXXXXXXXXXXXXXX |                  |          |          |                 |
| 0.0986           | 0.1034 | 0.0889 | 0.0986 | 0.1034 | 0.0889         | 0.0986 | 0.1034 |                      |                  |          |          |                 |
| 0.0914           | 0.0986 | 0.0792 | 0.0841 | 0.0914 | 0.0792         | 0.0841 | 0.0914 |                      |                  |          |          |                 |
| 0.0925           | 0.1022 | 0.0763 | 0.0812 | 0.0925 | 0.0763         | 0.0812 | 0.0925 | CYCLE3               | 0.0089           | 0.0334   | 3.4423   | 0.1151          |
| 0.0948           | 0.1021 | 0.0826 | 0.0826 | 0.0948 | 0.0826         | 0.0826 | 0.0948 |                      |                  | No       | Yes      | 0.0712          |
| 0.1082           | 0.1053 | 0.0934 | 0.0844 | 0.0973 | 0.0934         | 0.0844 | 0.0973 |                      |                  |          |          |                 |
| Mean             | 0.1090 | 0.1021 | 0.0903 | 0.0864 | 0.0903         | 0.0864 | 0.0993 |                      |                  |          |          |                 |
| Std Dev          | 0.0107 | 0.0030 | 0.0130 | 0.0105 | 0.0130         | 0.0105 | 0.0068 |                      |                  |          |          |                 |

| DATA SET 131-135 Alloy Code II |        |        |        |        |                      |                  |  |                                  |        | 90/95 Tolerance |        |
|--------------------------------|--------|--------|--------|--------|----------------------|------------------|--|----------------------------------|--------|-----------------|--------|
| STUD1                          | STUD2  | STUD3  | STUD4  | STUD5  | MEAN<br>VALUE        | STD<br>DEVIATION | TEST for<br>Mean<br>95% Confidence<br>t*= 1.68 | TEST for<br>Variance<br>F*= 1.98 |        |                 |        |
| 0.1421                         | 0.1469 | 0.1469 | 0.1662 | 0.1662 |                      |                  |  |                                  |        |                 |        |
| 0.1325                         | 0.1325 | 0.1640 | 0.1591 | 0.1664 |                      |                  |  |                                  |        |                 |        |
| 0.1362                         | 0.1394 | 0.1653 | 0.1588 | 0.1927 | RUN-IN               | 0.1596           | 0.0151   |                                  |        | 0.1970          | 0.1221 |
| 0.1522                         | 0.1571 | 0.1726 | 0.1644 | 0.1714 |                      |                  |  |                                  |        |                 |        |
| 0.1662                         | 0.1671 | 0.1756 | 0.1709 | 0.1766 | XXXXXXXXXXXXXXXXXXXX |                  |  |                                  |        |                 |        |
|                                | 0.1276 | 0.1421 | 0.1324 | 0.1566 |                      |                  |  |                                  |        |                 |        |
|                                | 0.1107 | 0.1277 | 0.1204 | 0.1277 |                      |                  |  |                                  |        |                 |        |
|                                | 0.1168 | 0.1314 | 0.1168 | 0.1265 | DESIGN               | 0.1261           | 0.0097   | 0.6754                           | 2.4468 | 0.1500          | 0.1021 |
|                                | 0.1082 | 0.1229 | 0.1229 | 0.1266 |                      |                  |  | No                               | Yes    |                 |        |
|                                | 0.1182 | 0.1182 | 0.1290 | 0.1231 | XXXXXXXXXXXXXXXXXXXX |                  |  |                                  |        |                 |        |
|                                | 0.1131 | 0.1228 | 0.1228 | 0.1179 |                      |                  |  |                                  |        |                 |        |
|                                | 0.1011 | 0.0986 | 0.1083 | 0.1035 |                      |                  |  |                                  |        |                 |        |
|                                | 0.1006 | 0.0957 | 0.1087 | 0.1071 | CYCLE3               | 0.1102           | 0.0082   | 0.4459                           | 1.4089 | 0.1303          | 0.0900 |
|                                | 0.1070 | 0.0972 | 0.1082 | 0.1119 |                      |                  |  | No                               | No     |                 |        |
|                                | 0.1102 | 0.1063 | 0.1142 | 0.1182 |                      |                  |  |                                  |        |                 |        |
| Mean                           | 0.1228 | 0.1271 | 0.1339 | 0.1359 |                      |                  |  |                                  |        |                 |        |
| Std Dev                        | 0.0194 | 0.0216 | 0.0245 | 0.0238 |                      |                  |  |                                  |        |                 |        |

| DATA SET 136-140 |        |        |        | Alloy Code SS |        | Studs 136-139 only   |       | MEAN<br>VALUE | STD<br>DEVIATION | TEST for          |          | 90/95 Tolerance |
|------------------|--------|--------|--------|---------------|--------|----------------------|-------|---------------|------------------|-------------------|----------|-----------------|
| STUD1            | STUD2  | STUD3  | STUD4  | STUD5         | STUD6  | STUD7                | STUD8 |               |                  | Mean              | Variance |                 |
| 0.1293           | 0.1223 | 0.1362 | 0.1129 | 0.1176        |        |                      |       |               |                  | t*=1.70           | F*=2.47  |                 |
| 0.1333           | 0.1333 | 0.1533 | 0.1309 | 0.1144        |        |                      |       |               |                  |                   |          |                 |
| 0.1185           | 0.1285 | 0.1446 | 0.1285 | 0.1185        | RUN-IN |                      |       | 0.1296        | 0.0104           |                   |          | 0.1579          |
| 0.1157           | 0.1258 | 0.1313 | ERR    | ERR           | ERR    |                      |       |               |                  |                   |          | 0.1013          |
| ERR              | ERR    | ERR    | ERR    | ERR           | ERR    | XXXXXXXXXXXXXXXXXXXX |       |               |                  |                   |          |                 |
| 0.0990           | 0.0873 | 0.0966 | 0.0756 | 0.0733        |        |                      |       |               |                  | DESIGN vs RUN-IN  |          |                 |
| 0.1003           | 0.1062 | 0.0908 | 0.0885 | 0.0861        |        |                      |       |               |                  | t                 | F        |                 |
| 0.1022           | 0.1108 | 0.1038 | 0.1046 | 0.0902        | DESIGN |                      |       | 0.0999        | 0.0105           | 0.7095            | 0.9852   | 0.1284          |
| 0.1084           | 0.1140 | 0.1101 | ERR    | ERR           | ERR    |                      |       |               |                  | No                | No       | 0.0713          |
| ERR              | ERR    | ERR    | ERR    | ERR           | ERR    | XXXXXXXXXXXXXXXXXXXX |       |               |                  |                   |          |                 |
| 0.0709           | 0.0756 | 0.0826 | 0.0990 | 0.0756        |        |                      |       |               |                  | DESIGN vs CYCLE 3 |          |                 |
| 0.0838           | 0.0979 | 0.0861 | 0.1003 | 0.0779        |        |                      |       |               |                  | t                 | F        |                 |
| 0.0942           | 0.1108 | 0.0950 | 0.1100 | 0.0797        | CYCLE3 |                      |       | 0.0967        | 0.0141           | 0.0647            | 0.5553   | 0.1350          |
| 0.1017           | 0.1157 | 0.1028 | 0.1207 | 0.0794        |        |                      |       |               |                  | No                | No       | 0.0584          |
| ERR              | ERR    | ERR    | ERR    | ERR           | ERR    |                      |       |               |                  |                   |          |                 |
| Mean             | 0.1048 | 0.1107 | 0.1071 | 0.0932        |        |                      |       |               |                  |                   |          |                 |
| Std Dev          | 0.0178 | 0.0170 | 0.0174 | 0.0179        |        |                      |       |               |                  |                   |          |                 |

| DATA SET 141-145 |        |        |        | Alloy Code T |                      | STUD5  | STUD4  | STUD3   | MEAN<br>VALUE | STD<br>DEVIATION | TEST for          | TEST for | 90/95 Tolerance |
|------------------|--------|--------|--------|--------------|----------------------|--------|--------|---------|---------------|------------------|-------------------|----------|-----------------|
| STUD1            | STUD2  | STUD3  | STUD4  | STUD5        | Mean                 |        |        |         |               |                  | Variance          |          |                 |
| 0.1064           | 0.1015 | 0.1064 | 0.1039 | 0.1088       |                      |        |        |         |               |                  | 95% Confidence    |          |                 |
| 0.1136           | 0.1062 | 0.1148 | 0.1050 | 0.1087       |                      |        |        |         |               |                  | t*= 1.68          | F*=1.98  |                 |
| 0.1168           | 0.1128 | 0.1216 | 0.1063 | 0.1144       | RUN-IN               | 0.1147 | 0.0097 |         |               |                  |                   | = 0.505  | 0.1386          |
| 0.1139           | 0.1197 | 0.1273 | 0.1080 | 0.1150       |                      |        |        |         |               |                  |                   |          | 0.0908          |
| 0.1244           | 0.1267 | 0.1411 | 0.1134 | 0.1314       | XXXXXXXXXXXXXXXXXXXX |        |        |         |               |                  |                   |          |                 |
| 0.0991           | 0.0942 | 0.0966 | 0.0796 | 0.0918       |                      |        |        |         |               |                  | DESIGN vs RUN-IN  |          |                 |
| 0.0989           | 0.1038 | 0.1026 | 0.0829 | 0.0940       |                      |        |        |         |               |                  | t                 | F        |                 |
| 0.1038           | 0.1095 | 0.1216 | 0.0954 | 0.1038       | DESIGN               | 0.1058 | 0.0141 | 0.1868  | 0.4683        |                  | No                | Yes      | 0.1408          |
| 0.1038           | 0.1174 | 0.1261 | 0.1019 | 0.1080       |                      |        |        |         |               |                  |                   |          | 0.0709          |
| 0.1121           | 0.1309 | 0.1392 | 0.1116 | 0.1176       | XXXXXXXXXXXXXXXXXXXX |        |        |         |               |                  |                   |          |                 |
| 0.0820           | 0.0966 | 0.1039 | 0.1015 | 0.1039       |                      |        |        |         |               |                  | DESIGN vs CYCLE 3 |          |                 |
| 0.0903           | 0.1026 | 0.1075 | 0.0940 | 0.1050       |                      |        |        |         |               |                  | t                 | F        |                 |
| 0.0937           | 0.1071 | 0.1176 | 0.0987 | 0.1144       | CYCLE3               | 0.1078 | 0.0136 | -0.0357 | 1.0847        |                  | No                | No       | 0.0743          |
| 0.0977           | 0.1226 | 0.1273 | 0.1038 | 0.1156       |                      |        |        |         |               |                  |                   |          |                 |
| 0.1052           | 0.1343 | 0.1377 | 0.1103 | 0.1221       |                      |        |        |         |               |                  |                   |          |                 |
| Mean             | 0.1041 | 0.1124 | 0.1184 | 0.1103       |                      |        |        |         |               |                  |                   |          |                 |
| Std Dev          | 0.0110 | 0.0124 | 0.0140 | 0.0098       |                      |        |        |         |               |                  |                   |          |                 |

| DATA SET 146-150 |        |        |        |        | Alloy Code AZ |                      | MEAN<br>VALUE | STD<br>DEVIATION | TEST for<br>Mean<br>95% Confidence | TEST for<br>Variance<br>F* | 90/95 Tolerance |
|------------------|--------|--------|--------|--------|---------------|----------------------|---------------|------------------|------------------------------------|----------------------------|-----------------|
| STUD1            | STUD2  | STUD3  | STUD4  | STUD5  | STUD3         | STUD4                |               |                  |                                    |                            |                 |
| 0.0931           | 0.1026 | 0.0900 | 0.1058 | 0.1090 |               |                      |               |                  |                                    |                            |                 |
| 0.0935           | 0.1078 | 0.0856 | 0.0840 | 0.1063 |               |                      |               |                  | t*= 1.68                           | F*=1.98                    |                 |
| 0.0930           | 0.1113 | 0.0898 | 0.0855 | 0.0984 |               | RUN-IN               | 0.0966        | 0.0090           |                                    | = 0.505                    | 0.1189          |
| 0.0962           | 0.1130 | 0.0896 | 0.0888 | 0.0954 |               |                      |               |                  |                                    |                            | 0.0742          |
| 0.0936           | 0.1108 | 0.0911 | 0.0879 | 0.0917 |               | XXXXXXXXXXXXXXXXXXXX |               |                  |                                    |                            |                 |
| 0.0773           | 0.0931 | 0.0773 | 0.0741 | 0.0773 |               |                      |               |                  | DESIGN vs RUN-IN                   |                            |                 |
| 0.0808           | 0.0951 | 0.0665 | 0.0776 | 0.0792 |               |                      |               |                  | t                                  | F                          |                 |
| 0.0877           | 0.0984 | 0.0780 | 0.0866 | 0.0855 |               | DESIGN               | 0.0838        | 0.0088           | 0.3567                             | 1.0523                     | 0.1056          |
| 0.0880           | 0.1011 | 0.0749 | 0.0872 | 0.0839 |               |                      |               |                  | No                                 | No                         |                 |
| 0.0848           | 0.1013 | 0.0756 | 0.0816 | 0.0828 |               | XXXXXXXXXXXXXXXXXXXX |               |                  |                                    |                            |                 |
| 0.0805           | 0.1058 | 0.0709 | 0.0678 | 0.0773 |               |                      |               |                  | DESIGN vs CYCLE 3                  |                            |                 |
| 0.0776           | 0.0935 | 0.0617 | 0.0649 | 0.0745 |               |                      |               |                  | t                                  | F                          |                 |
| 0.0887           | 0.0952 | 0.0726 | 0.0769 | 0.0791 |               | CYCLE3               | 0.0807        | 0.0105           | 0.0815                             | 0.7087                     | 0.1066          |
| 0.0896           | 0.0929 | 0.0732 | 0.0798 | 0.0782 |               |                      |               |                  | No                                 | No                         | 0.0548          |
| 0.0873           | 0.0936 | 0.0743 | 0.0816 | 0.0796 |               |                      |               |                  |                                    |                            |                 |
| Mean             | 0.0875 | 0.1010 | 0.0820 | 0.0865 |               |                      |               |                  |                                    |                            |                 |
| Std Dev          | 0.0061 | 0.0072 | 0.0092 | 0.0110 |               |                      |               |                  |                                    |                            |                 |

| DATA SET 151-155 |        |        |        |        | Alloy Code AR1       |                  | 90/95 Tolerance                    |                      |        |  |
|------------------|--------|--------|--------|--------|----------------------|------------------|------------------------------------|----------------------|--------|--|
| STUD1            | STUD2  | STUD3  | STUD4  | STUD5  | MEAN<br>VALUE        | STD<br>DEVIATION | TEST for<br>Mean<br>95% Confidence | TEST for<br>Variance |        |  |
| 0.1108           | 0.1152 | 0.1242 | 0.1152 | 0.1242 |                      |                  |                                    |                      |        |  |
| 0.1117           | 0.1159 | 0.1159 | 0.1138 | 0.1180 |                      |                  | t*= 1.68                           | F*=1.98              |        |  |
| 0.1073           | 0.1192 | 0.1221 | 0.1206 | 0.1132 | RUN-IN               | 0.1167           | 0.0054                             | = 0.505              | 0.1301 |  |
| 0.1078           | 0.1210 | 0.1188 | 0.1221 | 0.1122 |                      |                  |                                    |                      | 0.1033 |  |
| 0.1125           | 0.1178 | 0.1178 | 0.1291 | 0.1108 | XXXXXXXXXXXXXXXXXXXX |                  |                                    |                      |        |  |
| 0.1065           | 0.1065 | 0.1021 | 0.1065 | 0.1108 |                      |                  | DESIGN vs RUN-IN                   |                      |        |  |
| 0.1095           | 0.1095 | 0.1050 | 0.1138 | 0.1138 |                      |                  | t                                  | F                    |        |  |
| 0.1044           | 0.1118 | 0.1103 | 0.1147 | 0.1073 | DESIGN               | 0.1108           | 0.0045                             | 0.2970               | 1.4310 |  |
| 0.1100           | 0.1089 | 0.1122 | 0.1155 | 0.1089 |                      |                  | No                                 | No                   | 0.0996 |  |
| 0.1143           | 0.1134 | 0.1169 | 0.1221 | 0.1151 | XXXXXXXXXXXXXXXXXXXX |                  |                                    |                      |        |  |
| 0.1021           | 0.1065 | 0.1065 | 0.1108 | 0.1152 |                      |                  | DESIGN vs CYCLE 3                  |                      |        |  |
| 0.1074           | 0.1095 | 0.1050 | 0.1138 | 0.1222 |                      |                  | t                                  | F                    |        |  |
| 0.1088           | 0.1162 | 0.1088 | 0.1118 | 0.1192 | CYCLE3               | 0.1117           | 0.0051                             | -0.0452              | 0.7886 |  |
| 0.1067           | 0.1188 | 0.1078 | 0.1199 | 0.1111 |                      |                  | No                                 | No                   | 0.1242 |  |
| 0.1116           | 0.1116 | 0.1108 | 0.1169 | 0.1125 |                      |                  |                                    |                      | 0.0991 |  |
|                  |        |        |        |        |                      |                  |                                    |                      |        |  |
| Mean             | 0.1088 | 0.1135 | 0.1123 | 0.1164 |                      |                  |                                    |                      |        |  |
| Std Dev          | 0.0032 | 0.0047 | 0.0067 | 0.0056 |                      |                  |                                    |                      |        |  |

90/95 Tolerance

MEAN  
VALUE

Alloy Code MA

DATA SET 156-160

STUD1

| STUD1  | STUD2  | STUD3  | STUD4  | STUD5  | MEAN<br>VALUE        | STD<br>DEVIATION | TEST for<br>Mean<br>95% Confidence | TEST for<br>Variance<br>F* | 90/95 Tolerance |
|--------|--------|--------|--------|--------|----------------------|------------------|------------------------------------|----------------------------|-----------------|
| 0.0900 | 0.1152 | 0.1102 | 0.1102 | 0.1001 |                      |                  |                                    |                            |                 |
| 0.0860 | 0.1088 | 0.0988 | 0.1063 | 0.0913 |                      |                  | t*= 1.68                           | F*=1.98                    |                 |
| 0.0869 | 0.1094 | 0.1043 | 0.0999 | 0.0978 | RUN-IN               | 0.1078           | 0.0133                             |                            | 0.1408          |
| 0.0989 | 0.1118 | 0.1196 | 0.1092 | 0.1079 |                      |                  |                                    |                            | 0.0749          |
| 0.1165 | 0.1175 | 0.1340 | 0.1360 | 0.1299 | XXXXXXXXXXXXXXXXXXXX |                  |                                    |                            |                 |
| 0.0900 | 0.1203 | 0.1102 | 0.1051 | 0.1152 |                      |                  |                                    |                            |                 |
| 0.0888 | 0.1173 | 0.1038 | 0.0938 | 0.1063 |                      |                  |                                    |                            |                 |
| 0.0999 | 0.1065 | 0.1021 | 0.1065 | 0.1021 | DESIGN               | 0.1064           | 0.0085                             | 0.0340                     | 2.4407          |
| 0.1053 | 0.1105 | 0.1066 | 0.1053 | 0.0963 |                      |                  | No                                 | Yes                        | 0.1275          |
| 0.1062 | 0.1072 | 0.1186 | 0.1186 | 0.1165 | XXXXXXXXXXXXXXXXXXXX |                  |                                    |                            | 0.0853          |
| 0.1051 | 0.0950 | 0.1001 | 0.1051 | 0.0950 |                      |                  |                                    |                            |                 |
| 0.0913 | 0.0860 | 0.0988 | 0.1038 | 0.0963 |                      |                  |                                    |                            |                 |
| 0.0934 | 0.0836 | 0.0978 | 0.1094 | 0.1065 | CYCLE3               | 0.1011           | 0.0084                             | 0.1559                     | 1.0425          |
| 0.0976 | 0.0989 | 0.0976 | 0.1118 | 0.1028 |                      |                  | No                                 | No                         | 0.1218          |
| 0.1083 | 0.1000 | 0.1134 | 0.1144 | 0.1155 |                      |                  |                                    |                            | 0.0804          |

DESIGN vs RUN-IN

t

No

F

Yes

DESIGN vs CYCLE 3

t

No

F

No

Mean

Std Dev

90/95 Tolerance

MEAN  
VALUE

Alloy Code MA

DATA SET 156-160

STUD1

| STUD1  | STUD2  | STUD3  | STUD4  | STUD5  | MEAN<br>VALUE        | STD<br>DEVIATION | TEST for<br>Mean<br>95% Confidence | TEST for<br>Variance<br>F* | 90/95 Tolerance |
|--------|--------|--------|--------|--------|----------------------|------------------|------------------------------------|----------------------------|-----------------|
| 0.0900 | 0.1152 | 0.1102 | 0.1102 | 0.1001 |                      |                  |                                    |                            |                 |
| 0.0860 | 0.1088 | 0.0988 | 0.1063 | 0.0913 |                      |                  | t*= 1.74                           | F*=2.27                    |                 |
| 0.0869 | 0.1094 | 0.1043 | 0.0999 | 0.0978 | RUN-IN               | 0.1031           | 0.0094                             |                            | 0.1273          |
| 0.0989 | 0.1118 | 0.1196 | 0.1092 | 0.1079 |                      |                  |                                    |                            | 0.0789          |
| 0.0900 | 0.1203 | 0.1102 | 0.1051 | 0.1152 | XXXXXXXXXXXXXXXXXXXX |                  |                                    |                            |                 |
| 0.0888 | 0.1173 | 0.1038 | 0.0938 | 0.1063 |                      |                  |                                    |                            |                 |
| 0.0999 | 0.1065 | 0.1021 | 0.1065 | 0.1021 | DESIGN               | 0.1046           | 0.0082                             | -0.0420                    | 1.3146          |
| 0.1053 | 0.1105 | 0.1066 | 0.1053 | 0.0963 |                      |                  | No                                 | No                         | 0.1257          |
| 0.1051 | 0.0950 | 0.1001 | 0.1051 | 0.0950 | XXXXXXXXXXXXXXXXXXXX |                  |                                    |                            | 0.0835          |
| 0.0913 | 0.0860 | 0.0988 | 0.1038 | 0.0963 |                      |                  |                                    |                            |                 |
| 0.0934 | 0.0836 | 0.0978 | 0.1094 | 0.1065 | CYCLE3               | 0.0988           | 0.0072                             | 0.1886                     | 1.3100          |
| 0.0976 | 0.0989 | 0.0976 | 0.1118 | 0.1028 |                      |                  | No                                 | No                         | 0.1172          |

DESIGN vs RUN-IN

t

No

F

No

DESIGN vs CYCLE 3

t

No

F

No

\* Excludes the highest torque increment, see discussion  
under the Monel K-500 section of Phase II Test Results.

Mean

Std Dev



| DATA SET 166-170 |        |        |        | Alloy Code AS |                      |           |        | MEAN              | STD    | TEST for | TEST for | 90/95 Tolerance |
|------------------|--------|--------|--------|---------------|----------------------|-----------|--------|-------------------|--------|----------|----------|-----------------|
| STUD1            | STUD2  | STUD3  | STUD4  | STUD5         | VALUE                | DEVIATION | Mean   | Variance          |        |          |          |                 |
| 0.0827           | 0.0752 | 0.0559 | 0.0660 | 0.1127        |                      |           |        | 95% Confidence    |        |          |          |                 |
| 0.0892           | 0.0736 | 0.0750 | 0.0712 | 0.1286        |                      |           |        | t*= 1.701         |        |          |          |                 |
| 0.1130           | 0.0831 | 0.1093 | 0.0926 | 0.1339        | RUN-IN               |           |        | F*=2.49           |        |          |          |                 |
| ERR              | ERR    | ERR    | ERR    | ERR           |                      | 0.0908    | 0.0235 |                   |        |          |          | 0.1546          |
| ERR              | ERR    | ERR    | ERR    | ERR           | XXXXXXXXXXXXXXXXXXXX |           |        |                   |        |          |          | 0.0270          |
| 0.0715           | 0.0752 | 0.0550 | 0.0715 | 0.0921        |                      |           |        | DESIGN vs RUN-IN  |        |          |          |                 |
| 0.0750           | 0.0717 | 0.0622 | 0.0712 | 0.1004        |                      |           |        | t                 |        |          |          |                 |
| 0.0936           | 0.0763 | 0.0831 | 0.0923 | 0.1151        | DESIGN               |           |        | F                 |        |          |          |                 |
| ERR              | ERR    | ERR    | ERR    | ERR           |                      | 0.0804    | 0.0157 | 0.1327            | 2.2575 |          |          | 0.1229          |
| ERR              | ERR    | ERR    | ERR    | ERR           | XXXXXXXXXXXXXXXXXXXX |           |        | No                | No     |          |          | 0.0380          |
| 0.0651           | 0.0734 | 0.0541 | 0.0762 | 0.0846        |                      |           |        | DESIGN vs CYCLE 3 |        |          |          |                 |
| 0.0693           | 0.0755 | 0.0622 | 0.0726 | 0.0826        |                      |           |        | t                 |        |          |          |                 |
| 0.0864           | 0.0800 | 0.0854 | 0.0847 | 0.1023        | CYCLE3               |           |        | F                 |        |          |          |                 |
| ERR              | ERR    | ERR    | ERR    | ERR           |                      | 0.0770    | 0.0118 | 0.0633            | 1.7731 |          |          | 0.1089          |
| ERR              | ERR    | ERR    | ERR    | ERR           |                      |           |        | No                | No     |          |          | 0.0451          |
| Mean             | 0.0829 | 0.0760 | 0.0714 | 0.0776        |                      |           |        |                   |        |          |          |                 |
| Std Dev          | 0.0149 | 0.0035 | 0.0186 | 0.0098        |                      |           |        |                   |        |          |          |                 |

| DATA SET 171 Only 1 Stud |        |        |        |        | Alloy Code IMC2 |  |  |
|--------------------------|--------|--------|--------|--------|-----------------|--|--|
| STUD1                    | STUD2  | STUD3  | STUD4  | STUD5  |                 |  |  |
| 0.1276                   | 0.0000 | 0.0000 | 0.0000 | 0.0000 |                 |  |  |
| 0.0962                   | 0.0000 | 0.0000 | 0.0000 | 0.0000 |                 |  |  |
| 0.0909                   | 0.0000 | 0.0000 | 0.0000 | 0.0000 | RUN-IN          |  |  |
| 0.0948                   | 0.0000 | 0.0000 | 0.0000 | 0.0000 |                 |  |  |
| 0.1013                   | 0.0000 | 0.0000 | 0.0000 | 0.0000 | XXXXXXXXXX      |  |  |
| 0.1082                   | 0.0000 | 0.0000 | 0.0000 | 0.0000 |                 |  |  |
| 0.0962                   | 0.0000 | 0.0000 | 0.0000 | 0.0000 |                 |  |  |
| 0.0990                   | 0.0000 | 0.0000 | 0.0000 | 0.0000 | DESIGN          |  |  |
| 0.1009                   | 0.0000 | 0.0000 | 0.0000 | 0.0000 |                 |  |  |
| 0.1053                   | 0.0000 | 0.0000 | 0.0000 | 0.0000 | XXXXXXXXXX      |  |  |
| 0.0986                   | 0.0000 | 0.0000 | 0.0000 | 0.0000 |                 |  |  |
| 0.0914                   | 0.0000 | 0.0000 | 0.0000 | 0.0000 |                 |  |  |
| 0.0941                   | 0.0000 | 0.0000 | 0.0000 | 0.0000 | CYCLE3          |  |  |
| 0.1058                   | 0.0000 | 0.0000 | 0.0000 | 0.0000 |                 |  |  |
| 0.1082                   | 0.0000 | 0.0000 | 0.0000 | 0.0000 |                 |  |  |
| Mean                     | 0.1012 | 0.0000 | 0.0000 | 0.0000 |                 |  |  |
| Std Dev                  | 0.0092 | 0.0000 | 0.0000 | 0.0000 |                 |  |  |

| DATA SET 176 Only 1 Stud |        |       |       |       | Alloy Code IMC3 |  |  |
|--------------------------|--------|-------|-------|-------|-----------------|--|--|
| STUD1                    | STUD2  | STUD3 | STUD4 | STUD5 |                 |  |  |
| 0.1179                   | ERR    | ERR   | ERR   | ERR   |                 |  |  |
| 0.1035                   | ERR    | ERR   | ERR   | ERR   |                 |  |  |
| 0.1038                   | ERR    | ERR   | ERR   | ERR   | RUN-IN          |  |  |
| 0.1070                   | ERR    | ERR   | ERR   | ERR   |                 |  |  |
| 0.1122                   | ERR    | ERR   | ERR   | ERR   | XXXXXXXXXX      |  |  |
| 0.1179                   | ERR    | ERR   | ERR   | ERR   |                 |  |  |
| 0.1083                   | ERR    | ERR   | ERR   | ERR   |                 |  |  |
| 0.1022                   | ERR    | ERR   | ERR   | ERR   | DESIGN          |  |  |
| 0.0997                   | ERR    | ERR   | ERR   | ERR   |                 |  |  |
| 0.1033                   | ERR    | ERR   | ERR   | ERR   | XXXXXXXXXX      |  |  |
| 0.1082                   | ERR    | ERR   | ERR   | ERR   |                 |  |  |
| 0.1011                   | ERR    | ERR   | ERR   | ERR   |                 |  |  |
| 0.1006                   | ERR    | ERR   | ERR   | ERR   | CYCLE3          |  |  |
| 0.0997                   | ERR    | ERR   | ERR   | ERR   |                 |  |  |
| 0.1023                   | ERR    | ERR   | ERR   | ERR   |                 |  |  |
| Mean                     | 0.1059 | ERR   | ERR   | ERR   |                 |  |  |
| Std Dev                  | 0.0061 | ERR   | ERR   | ERR   |                 |  |  |

| DATA SET 181 Only 1 Stud |        |        |        |        | Alloy Code IMA |  |  |
|--------------------------|--------|--------|--------|--------|----------------|--|--|
| STUD1                    | STUD2  | STUD3  | STUD4  | STUD5  |                |  |  |
| 0.0784                   | 0.0000 | 0.0000 | 0.0000 | 0.0000 |                |  |  |
| 0.0824                   | 0.0000 | 0.0000 | 0.0000 | 0.0000 |                |  |  |
| 0.0999                   | 0.0000 | 0.0000 | 0.0000 | 0.0000 | RUN-IN         |  |  |
| 0.1117                   | 0.0000 | 0.0000 | 0.0000 | 0.0000 |                |  |  |
| ERR                      | 0.0000 | 0.0000 | 0.0000 | 0.0000 | XXXXXXXXXX     |  |  |
| 0.0784                   | 0.0000 | 0.0000 | 0.0000 | 0.0000 |                |  |  |
| 0.0847                   | 0.0000 | 0.0000 | 0.0000 | 0.0000 |                |  |  |
| 0.0985                   | 0.0000 | 0.0000 | 0.0000 | 0.0000 | DESIGN         |  |  |
| 0.1081                   | 0.0000 | 0.0000 | 0.0000 | 0.0000 |                |  |  |
| ERR                      | 0.0000 | 0.0000 | 0.0000 | 0.0000 | XXXXXXXXXX     |  |  |
| 0.0923                   | 0.0000 | 0.0000 | 0.0000 | 0.0000 |                |  |  |
| 0.0985                   | 0.0000 | 0.0000 | 0.0000 | 0.0000 |                |  |  |
| 0.1079                   | 0.0000 | 0.0000 | 0.0000 | 0.0000 | CYCLE3         |  |  |
| 0.1117                   | 0.0000 | 0.0000 | 0.0000 | 0.0000 |                |  |  |
| 0.1114                   | 0.0000 | 0.0000 | 0.0000 | 0.0000 |                |  |  |
| Mean                     | 0.0972 | 0.0000 | 0.0000 | 0.0000 |                |  |  |
| Std Dev                  | 0.0128 | 0.0000 | 0.0000 | 0.0000 |                |  |  |

| DATA SET 186 Alloy Code IMB |        |     |       |     |       |     |       |     |                  |
|-----------------------------|--------|-----|-------|-----|-------|-----|-------|-----|------------------|
| STUD1                       | STUD2  |     | STUD3 |     | STUD4 |     | STUD5 |     |                  |
| 0.1009                      | ERR    | ERR |       |     | ERR   | ERR | ERR   | ERR | ERR              |
| 0.1102                      | ERR    | ERR |       |     | ERR   | ERR | ERR   | ERR | ERR              |
| 0.1286                      | ERR    | ERR |       |     | ERR   | ERR | ERR   | ERR | ERR RUN-IN       |
| 0.1280                      | ERR    | ERR |       |     | ERR   | ERR | ERR   | ERR | ERR              |
| ERR                         | ERR    | ERR |       |     | ERR   | ERR | ERR   | ERR | ERR XXXXXXXXXXXX |
|                             | 0.1009 | ERR |       | ERR | ERR   | ERR | ERR   | ERR | ERR              |
|                             | 0.1063 | ERR |       | ERR | ERR   | ERR | ERR   | ERR | ERR              |
|                             | 0.1192 | ERR |       | ERR | ERR   | ERR | ERR   | ERR | ERR DESIGN       |
|                             | 0.1207 | ERR |       | ERR | ERR   | ERR | ERR   | ERR | ERR              |
|                             | ERR    | ERR |       | ERR | ERR   | ERR | ERR   | ERR | ERR XXXXXXXXXXXX |
|                             | 0.0782 | ERR |       | ERR | ERR   | ERR | ERR   | ERR | ERR              |
|                             | 0.0964 | ERR |       | ERR | ERR   | ERR | ERR   | ERR | ERR              |
|                             | 0.1089 | ERR |       | ERR | ERR   | ERR | ERR   | ERR | ERR CYCLE3       |
|                             | 0.1191 | ERR |       | ERR | ERR   | ERR | ERR   | ERR | ERR              |
|                             | ERR    | ERR |       | ERR | ERR   | ERR | ERR   | ERR | ERR              |
| Mean                        | 0.1098 | ERR |       | ERR | ERR   | ERR | ERR   | ERR | ERR              |
| Std Dev                     | 0.0145 | ERR |       | ERR | ERR   | ERR | ERR   | ERR | ERR              |

| DATA SET 191-195 |        |        |        |        | Alloy Code MK        |        | MEAN<br>VALUE | STD<br>DEVIATION | TEST for<br>Mean<br>95% Confidence<br>t*= 1.68<br>F*=1.98 | TEST for<br>Variance<br>F | 90/95 Tolerance |
|------------------|--------|--------|--------|--------|----------------------|--------|---------------|------------------|---|---------------------------|-----------------|
| STUD1            | STUD2  | STUD3  | STUD4  | STUD5  |                      |        |               |                  |   |                           |                 |
| 0.1348           | 0.1186 | 0.1121 | 0.1380 | 0.1348 |                      |        |               |                  |   |                           |                 |
| 0.1256           | 0.1191 | 0.1093 | 0.1288 | 0.1272 |                      |        |               |                  |   |                           |                 |
| 0.1231           | 0.1253 | 0.1088 | 0.1253 | 0.1198 | RUN-IN               | 0.1205 | 0.0087        |                  | 0.505   |                           | 0.1420          |
| 0.1169           | 0.1210 | 0.1047 | 0.1202 | 0.1234 |                      |        |               |                  |   |                           | 0.0990          |
| 0.1147           | 0.1172 | 0.1056 | 0.1160 | 0.1229 | XXXXXXXXXXXXXXXXXXXX |        |               |                  |   |                           |                 |
| 0.1186           | 0.1510 | 0.1154 | 0.1283 | 0.1251 |                      |        |               | DESIGN vs RUN-IN |   |                           |                 |
| 0.1256           | 0.1386 | 0.1142 | 0.1288 | 0.1142 |                      |        |               | t                | F   |                           |                 |
| 0.1242           | 0.1275 | 0.1121 | 0.1297 | 0.1132 | DESIGN               | 0.1219 | 0.0098        | -0.0359          | 0.7783  |                           | 0.1462          |
| 0.1161           | 0.1314 | 0.1097 | 0.1242 | 0.1153 |                      |        |               | No               | No  |                           | 0.0975          |
| 0.1114           | 0.1272 | 0.1101 | 0.1191 | 0.1153 | XXXXXXXXXXXXXXXXXXXX |        |               |                  |   |                           |                 |
| 0.1121           | 0.1380 | 0.1154 | 0.1121 | 0.1186 |                      |        |               |                  |   |                           |                 |
| 0.1223           | 0.1272 | 0.1175 | 0.1191 | 0.1240 |                      |        |               |                  |   |                           |                 |
| 0.1187           | 0.1242 | 0.1198 | 0.1286 | 0.1286 | CYCLE3               | 0.1211 | 0.0067        | 0.0242           | 2.1413  |                           | 0.1044          |
| 0.1113           | 0.1250 | 0.1169 | 0.1258 | 0.1290 |                      |        |               | No               | Yes   |                           |                 |
| 0.1095           | 0.1185 | 0.1166 | 0.1210 | 0.1266 |                      |        |               |                  |   |                           |                 |
| Mean             | 0.1190 | 0.1273 | 0.1126 | 0.1243 |                      |        |               |                  |   |                           |                 |
| Std Dev          | 0.0070 | 0.0093 | 0.0045 | 0.0065 |                      |        |               |                  |   |                           |                 |



| DATA SET 201-205 |        |        |        |        | Alloy Code ICR       |  | STUD5 | STD<br>DEVIATION | TEST for<br>Mean<br>95% Confidence<br>t*=1.68 | TEST for<br>Variance<br>F*=1.98 | 90/95 Tolerance |
|------------------|--------|--------|--------|--------|----------------------|--|-------|------------------|---|---------------------------------|-----------------|
| STUD1            | STUD2  | STUD3  | STUD4  | STUD5  | MEAN<br>VALUE        |  |       |                  |   |                                 |                 |
| 0.1469           | 0.1131 | 0.1034 | 0.1082 | 0.1518 |                      |  |       |                  |   |                                 |                 |
| 0.1398           | 0.1011 | 0.0914 | 0.1011 | 0.1277 |                      |  |       |                  |   |                                 |                 |
| 0.1362           | 0.1022 | 0.0925 | 0.1006 | 0.1265 | RUN-IN               |  |       |                  |   |                                 |                 |
| 0.1363           | 0.1021 | 0.0985 | 0.0997 | 0.1241 |                      |  |       |                  |   |                                 | 0.1608          |
| 0.1396           | 0.1082 | 0.1053 | 0.1013 | 0.1290 | XXXXXXXXXXXXXXXXXXXX |  |       |                  |   |                                 | 0.0701          |
| 0.1228           | 0.1324 | 0.1034 | 0.1131 | 0.1131 |                      |  |       |                  |   |                                 |                 |
| 0.1107           | 0.1204 | 0.0914 | 0.0938 | 0.1035 |                      |  |       |                  |   |                                 |                 |
| 0.1071           | 0.1152 | 0.0925 | 0.0957 | 0.1006 | DESIGN               |  |       |                  |   |                                 |                 |
| 0.1180           | 0.1131 | 0.0936 | 0.0997 | 0.1034 |                      |  |       |                  |   |                                 | 0.1366          |
| 0.1300           | 0.1172 | 0.1013 | 0.1033 | 0.1132 | XXXXXXXXXXXXXXXXXXXX |  |       |                  |   |                                 | 0.0801          |
| 0.1034           | 0.1324 | 0.1082 | 0.1131 | 0.1179 |                      |  |       |                  |   |                                 |                 |
| 0.1059           | 0.1083 | 0.0986 | 0.0986 | 0.1035 |                      |  |       |                  |   |                                 |                 |
| 0.1119           | 0.1119 | 0.0990 | 0.1006 | 0.1038 | CYCLE3               |  |       |                  |   |                                 |                 |
| 0.1119           | 0.1131 | 0.0985 | 0.1046 | 0.1046 |                      |  |       |                  |   |                                 |                 |
| 0.1241           | 0.1211 | 0.1043 | 0.1082 | 0.1102 |                      |  |       |                  |   |                                 | 0.1297          |
|                  |        |        |        |        |                      |  |       |                  |   |                                 | 0.0878          |
| Mean             | 0.1230 | 0.1141 | 0.0988 | 0.1028 |                      |  |       |                  |   |                                 |                 |
| Std Dev          | 0.0143 | 0.0096 | 0.0055 | 0.0057 |                      |  |       |                  |   |                                 |                 |

Mean

Mean  
Std Dev



## **Appendix D**

### **ANTI-SEIZING TEST RESULTS**

TABLE 1 - ANTI-SEIZING TEST RESULTS

| TEST MATERIAL - TYPE 304 CRES |                    |     |     |     |     |                      |    |    |     |     |              |     |     |     |     |     |     |     |     |  |   |
|-------------------------------|--------------------|-----|-----|-----|-----|----------------------|----|----|-----|-----|--------------|-----|-----|-----|-----|-----|-----|-----|-----|--|---|
| LUBRICANT                     | TORQUE<br>(ft-lbs) |     |     |     |     |                      |    |    |     |     |              |     |     |     |     |     |     |     |     | BREAKAWAY TORQUE (ft-lbs) AFTER X WEEKS OF EXPOSURE AT 650°F |   |
|                               | INITIAL<br>RUN IN  |     |     |     |     | INITIAL<br>BREAKAWAY |    |    |     |     | INSTALLATION |     |     |     |     |     |     |     |     |  |   |
|                               |                    |     |     |     |     |                      |    |    |     |     | 1            | 3   | 6   | 10A | 10B | 1   | 3   | 6   | 10A |  |   |
|                               | 1                  | 3   | 6   | 10A | 10B | 1                    | 3  | 6  | 10A | 10B | 1            | 3   | 6   | 10A | 10B | 1   | 3   | 6   | 10  | 10   | B |
| N5000                         | 123                | 123 | 125 | 123 | 123 | 73                   | 75 | 75 | 72  | 73  | 125          | 123 | 123 | 122 | 118 | 478 | 505 | 610 | 600 |  |   |
| N1000                         | 126                | 125 | 125 | 125 | 125 | 83                   | 80 | 80 | 80  | 82  | 125          | 125 | 125 | 125 | 139 | 285 | 436 | 424 | 352 |  |   |
| Neolube<br>No. 650            | 124                | 125 | 125 | 125 | 125 | 67                   | 79 | 70 | 75  | 75  | 127          | 125 | 124 | 125 | 148 | 299 | 497 | 480 | 489 |  |   |
| NIKAL                         | 125                | 125 | 125 | 125 | 125 | 89                   | 86 | 89 | 89  | 86  | 125          | 126 | 125 | 125 | 159 | 540 | 479 | 468 | 464 |  |   |
| N2000                         | 125                | 124 | 125 | 125 | 125 | 78                   | 77 | 81 | 80  | 80  | 125          | 125 | 124 | 125 | 128 | 263 | 343 | 360 | 347 |  |   |
| Never Seez                    | 125                | 124 | 126 | 125 | 125 | 79                   | 81 | 81 | 80  | 80  | 125          | 124 | 127 | 126 | 137 | 508 | 590 | 625 | 630 |  |   |
| NM-91                         | 125                | 125 | 125 | 125 | 125 | 85                   | 90 | 85 | 90  | 89  | 126          | 125 | 126 | 124 | 147 | 297 | 491 | 453 | 289 |  |   |
| Molykote<br>P37               | 125                | 125 | 125 | 125 | 125 | 81                   | 90 | 82 | 86  | 86  | 125          | 125 | 125 | 125 | 119 | 199 | 319 | 268 | 250 |  |   |
| MDSI                          | 125                | 125 | 125 | 125 | 124 | 69                   | 70 | 70 | 66  | 70  | 126          | 125 | 125 | 124 | 94  | 110 | 180 | 148 | 132 |  |   |
| RLGMO                         | 126                | 125 | 125 | 125 | 126 | 80                   | 79 | 80 | 81  | 80  | 125          | 125 | 125 | 125 | 85  | 133 | 179 | 200 | 183 |  |   |

+ The needle on the torque wrench jumped indicating possible galling

TABLE 2 - ANTI-SEIZING TEST RESULTS

| TEST MATERIAL - K-MONEL/MONEL |  | TORQUE<br>(ft-lbs) |     |     |     |     |     |     |     |                   |     |     |     |     |     |     |     | BREAKAWAY TORQUE (ft-lbs) AFTER X WEEKS OF EXPOSURE AT 650°F |     |     |     |
|-------------------------------|--|--------------------|-----|-----|-----|-----|-----|-----|-----|-------------------|-----|-----|-----|-----|-----|-----|-----|--|-----|-----|-----|
| LUBRICANT                     |  | INITIAL RUN IN     |     |     |     |     |     |     |     | INITIAL BREAKAWAY |     |     |     |     |     |     |     | INSTALLATION   |     |     |     |
|                               |  | 1                  |     |     |     | 3   |     |     |     | 6                 |     |     |     | 10A |     |     |     | 1  |     |     |     |
|                               |  | 1                  | 3   | 6   | 10A | 10B | 1   | 3   | 6   | 10A               | 10B | 1   | 3   | 6   | 10A | 10B | 1   | 3  | 6   | 10  | 10  |
| N5000                         |  | 175                | 175 | 175 | 175 | 175 | 95  | 100 | 95  | 95                | 97  | 177 | 175 | 175 | 175 | 175 | 120 | 481  | 303 | 469 | 487 |
| N1000                         |  | 175                | 175 | 175 | 175 | 176 | 102 | 105 | 101 | 100               | 102 | 180 | 175 | 175 | 176 | 177 | 135 | 366  | 445 | 480 | 479 |
| Neolube No. 650               |  | 175                | 175 | 176 | 175 | 175 | 86  | 90  | 89  | 84                | 86  | 175 | 175 | 174 | 175 | 175 | 109 | 354  | 345 | 320 | 409 |
| NIKAL                         |  | 176                | 175 | 175 | 175 | 175 | 131 | 129 | 127 | 130               | 127 | 178 | 175 | 175 | 176 | 178 | 216 | 542  | 480 | 543 | 539 |
| N2000                         |  | 176                | 175 | 176 | 177 | 175 | 101 | 104 | 99  | 90                | 97  | 174 | 176 | 175 | 175 | 174 | 118 | 397  | 500 | 491 | 494 |
| Never Seez                    |  | 175                | 174 | 175 | 174 | 175 | 100 | 95  | 99  | 99                | 98  | 175 | 175 | 175 | 176 | 177 | 147 | 528  | 520 | 650 | 568 |
| NM-91                         |  | 175                | 175 | 177 | 176 | 175 | 127 | 132 | 130 | 140               | 136 | 177 | 175 | 175 | 175 | 175 | 243 | 386  | 400 | 387 | 304 |
| Molykote P37                  |  | 174                | 175 | 176 | 175 | 174 | 116 | 116 | 119 | 121               | 117 | 175 | 176 | 174 | 175 | 175 | 153 | 184  | 189 | 236 | 211 |
| MDSI                          |  | 175                | 176 | 175 | 175 | 175 | 91  | 87  | 87  | 90                | 86  | 174 | 175 | 175 | 175 | 175 | 155 | 200  | 185 | 200 | 212 |
| RLGMO                         |  | 176                | 175 | 176 | 175 | 176 | 105 | 104 | 104 | 106               | 106 | 175 | 176 | 176 | 177 | 175 | 131 | 173  | 210 | 242 | 239 |

+ The needle on the torque wrench jumped indicating possible galling

TABLE 3 - ANTI-SEIZING TEST RESULTS

| TEST MATERIAL - ALLOY STEEL |                    |     |     |     |     |                   |     |     |     |     |              |     |     |     |     |     |     |     |     |    |  |   |  |
|-----------------------------|--------------------|-----|-----|-----|-----|-------------------|-----|-----|-----|-----|--------------|-----|-----|-----|-----|-----|-----|-----|-----|----|--|---|--|
| LUBRICANT                   | TORQUE<br>(ft-lbs) |     |     |     |     |                   |     |     |     |     |              |     |     |     |     |     |     |     |     |    | BREAKAWAY TORQUE (ft-lbs) AFTER X WEEKS OF EXPOSURE AT 650°F |   |  |
|                             | INITIAL RUN IN     |     |     |     |     | INITIAL BREAKAWAY |     |     |     |     | INSTALLATION |     |     |     |     |     |     |     |     |    |  |   |  |
|                             | 1                  | 3   | 6   | 10A | 10B | 1                 | 3   | 6   | 10A | 10B | 1            | 3   | 6   | 10A | 10B | 1   | 3   | 6   | 10  | 10 | A  | B |  |
|                             |                    |     |     |     |     |                   |     |     |     |     |              |     |     |     |     |     |     |     |     |    |  |   |  |
| N5000                       | 230                | 230 | 230 | 230 | 231 | 155               | 135 | 150 | 150 | 160 | 230          | 230 | 230 | 230 | 232 | 275 | 321 | 284 | 283 |    |  |   |  |
| N1000                       | 230                | 230 | 230 | 230 | 230 | 150               | 151 | 150 | 151 | 155 | 231          | 229 | 230 | 230 | 232 | 227 | 338 | 245 | 255 |    |  |   |  |
| Neolube No.650              | 230                | 228 | 230 | 231 | 230 | 112               | 100 | 134 | 109 | 112 | 229          | 230 | 230 | 230 | 229 | 270 | 309 | 222 | 222 |    |  |   |  |
| NIKAL                       | 237                | 230 | 234 | 231 | 230 | 194               | 175 | 186 | 170 | 170 | 236          | 230 | 229 | 230 | 230 | 515 | 482 | 450 | 412 |    |  |   |  |
| N2000                       | 228                | 231 | 230 | 231 | 230 | 138               | 148 | 145 | 145 | 148 | 232          | 230 | 234 | 230 | 229 | 240 | 281 | 238 | 282 |    |  |   |  |
| Never Seez                  | 231                | 232 | 229 | 234 | 230 | 150               | 152 | 141 | 154 | 157 | 232          | 230 | 230 | 230 | 231 | 261 | 401 | 390 | 323 |    |  |   |  |
| NM-91                       | 230                | 230 | 230 | 230 | 231 | 171               | 170 | 165 | 169 | 180 | 231          | 231 | 229 | 230 | 230 | 299 | 422 | 309 | 350 |    |  |   |  |
| Molykote P37                | 228                | 231 | 229 | 230 | 232 | 151               | 160 | 157 | 156 | 157 | 228          | 230 | 230 | 231 | 230 | 202 | 244 | 250 | 263 |    |  |   |  |
| MDSI                        | 231                | 230 | 229 | 230 | 231 | 135               | 141 | 121 | 131 | 137 | 229          | 229 | 230 | 230 | 230 | 161 | 138 | 220 | 150 |    |  |   |  |
| RLGMO                       | 230                | 232 | 232 | 234 | 230 | 156               | 156 | 146 | 152 | 151 | 230          | 229 | 234 | 230 | 230 | 183 | 220 | 280 | 210 |    |  |   |  |

+ The needle on the torque wrench jumped indicating possible galling

## **Appendix E**

### **ANTI-GALLING TEST RESULTS**

TABLE 1 - ANTI-GALLING TEST RESULTS

| TEST MATERIAL:K-Monel/Monel TEST LOADS: CYCLES 1-8 22300 lbs. CYCLES 9-12 33500 lbs |  |      |      |      |     |     |     |     |     |     |     |     |                                      |                       |  |
|---|--|------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|--------------------------------------|-----------------------|--|
| LUBRICANT/<br>SPECIMEN  | INSTALLATION TORQUE VALUE PER TORQUING CYCLE (ft-lb) |      |      |      |     |     |     |     |     |     |     |     | NUMBER OF<br>TORQUINGS<br>TO GALLING | OTHER<br>OBSERVATIONS |  |
|   | 1  | 2    | 3    | 4    | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  |                                      |                       |  |
| No Lubricant  | 295  | *    |      |      |     |     |     |     |     |     |     |     | 2                                    | Seized                |  |
| N5000 -1<br>-2  | 193  | 219  | 228  | 220  | 251 | 211 | 205 | 228 | 340 | 309 | 308 | 316 | 12                                   |                       |  |
|   | 229  | 185  | 229  | 219  | 225 | 205 | 221 | 211 | 350 | 325 | 324 | 332 | 12                                   |                       |  |
| N1000 -1<br>-2  | 190  | 205  | 209  | 212  | 206 | 202 | 210 | 203 | 310 | 307 | 352 | 323 | 12                                   |                       |  |
|   | 240  | 218  | 245  | 221  | 239 | 222 | 220 | 222 | 380 | 348 | 352 | 338 | 12                                   |                       |  |
| Neolube -1<br>No. 650 -2  | 198  | 170  | 160  | 149  | 148 | 141 | 135 | 134 | 260 | 215 | 212 | 212 | 12                                   | Coats uneven          |  |
|   | 132  | 130  | 118  | 115  | 114 | 110 | 110 | 120 | 189 | 213 | 222 | 231 | 12                                   |                       |  |
| NIKAL -1<br>-2  | 320*   | 444* | 416* | 342* |     |     |     |     |     |     |     |     | 1                                    | Discontinued          |  |
|   | 303  | 375* | 410* | 355* |     |     |     |     |     |     |     |     | 2                                    | Discontinued          |  |
| N2000 -1<br>-2  | 233  | 195  | 178  | 175  | 216 | 219 | 193 | 203 | 360 | 352 | 338 | 301 | 12                                   |                       |  |
|   | 224  | 215  | 220  | 222  | 229 | 233 | 232 | 238 | 313 | 311 | 326 | 330 | 12                                   |                       |  |
| Never -1<br>Seez -2   | 229  | 197  | 199  | 200  | 185 | 202 | 200 | 221 | 469 | 403 | 395 | 380 | 12                                   |                       |  |
|   | 220  | 230  | 203  | 217  | 165 | 210 | 229 | 212 | 304 | 419 | 351 | 354 | 12                                   |                       |  |
| NM-91 -1<br>-2  | 274  | 274  | 256  | 243  | 250 | 255 | 242 | 232 | 458 | 409 | 400 | 364 | No Galling                           |                       |  |
|   | 320  | 284  | 284  | 254  | 272 | 260 | 245 | 249 | 439 | 369 | 330 | 312 | No Galling                           |                       |  |
| Molykote -1<br>P37 -2   | 211  | 209  | 210  | 210  | 209 | 211 | 221 | 210 | 380 | 403 | 360 | 350 | 12                                   |                       |  |
|   | 221  | 225  | 231  | 222  | 238 | 231 | 220 | 220 | 372 | 389 | 358 | 360 | 12                                   |                       |  |
| MDSI -1<br>-2   | 274  | 246  | 305  | 304  | 186 | 245 | 282 | 281 | 277 | 402 | 450 | 483 | 12                                   |                       |  |
|   | 221  | 192  | 239  | 276  | 223 | 235 | 251 | 315 | 332 | 382 | 462 | 494 | 12                                   |                       |  |
| RLGMO -1<br>-2  | 168  | 158  | 148  | 142  | 139 | 135 | 152 | 136 | 244 | 221 | 243 | 262 | 12                                   |                       |  |
|   | 186  | 132  | 121  | 130  | 136 | 132 | 132 | 134 | 203 | 253 | 250 | 250 | 12                                   |                       |  |

\* The needle on the torque wrench jumped accompanied by audible clicking indicating possible galling.

TABLE 2 - ANTI-GALLING TEST RESULTS

| TEST MATERIAL: K-Monel/Monel TEST LOADS: CYCLES 1-8 22300 lbs CYCLES 9-12 33500 lbs |   |      |      |      |     |     |     |     |     |     |     |     |                       |
|---|---|------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----------------------|
| LUBRICANT/<br>SPECIMEN  | BREAKAWAY TORQUE VALUE PER TORQUING CYCLE (ft-lb) |      |      |      |     |     |     |     |     |     |     |     | OTHER<br>OBSERVATIONS |
|   | 1   | 2    | 3    | 4    | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  |                       |
| No Lubricant  | *   | *    |      |      |     |     |     |     |     |     |     |     | Seized                |
| N5000 -1  | 129   | 151  | 171  | 158  | 159 | 158 | 144 | 165 | 240 | 215 | 211 | 228 |                       |
| -2  | 142   | 139  | 134  | 149  | 135 | 140 | 138 | 140 | 220 | 220 | 212 | 233 |                       |
| N1000 -1  | 138   | 149  | 150  | 151  | 149 | 149 | 150 | 149 | 210 | 219 | 231 | 221 |                       |
| -2  | 162   | 150  | 162  | 163  | 160 | 155 | 160 | 151 | 245 | 235 | 249 | 236 |                       |
| Neolube -1  | 130   | 123  | 110  | 101  | 93  | 89  | 82  | 81  | 144 | 147 | 135 | 129 |                       |
| No. 650 -2  | 82  | 76   | 72   | 70   | 68  | 60  | 63  | 77  | 118 | 140 | 130 | 135 |                       |
| NIKAL -1  | 247*  | 360* | 380* | 320* |     |     |     |     |     |     |     |     | Discontinued          |
| -2  | 205   | 279  | 350* | 305* |     |     |     |     |     |     |     |     | Discontinued          |
| N2000 -1  | 129   | 105  | 100  | 105  | 128 | 132 | 130 | 120 | 240 | 226 | 211 | 194 |                       |
| -2  | 138   | 128  | 136  | 135  | 142 | 149 | 141 | 145 | 199 | 182 | 195 | 200 |                       |
| Never -1  | 165   | 140  | 149  | 142  | 134 | 145 | 135 | 151 | 325 | 294 | 294 | 279 |                       |
| Seez -2   | 161   | 169  | 138  | 150  | 112 | 140 | 163 | 157 | 218 | 265 | 249 | 253 |                       |
| NIM-91 -1   | 215   | 215  | 192  | 180  | 189 | 197 | 175 | 171 | 315 | 291 | 260 | 268 |                       |
| -2  | 239   | 220  | 205  | 189  | 211 | 199 | 185 | 185 | 340 | 265 | 233 | 225 |                       |
| Molykote -1   | 140   | 140  | 131  | 133  | 142 | 139 | 139 | 137 | 259 | 238 | 228 | 228 |                       |
| P37 -2  | 170   | 166  | 161  | 160  | 168 | 161 | 154 | 151 | 260 | 269 | 250 | 237 |                       |
| MDSI -1   | 182   | 159  | 168  | 178  | 135 | 185 | 189 | 219 | 185 | 255 | 296 | 333 |                       |
| -2  | 161   | 142  | 161  | 169  | 163 | 170 | 184 | 215 | 223 | 245 | 315 | 335 |                       |
| RLGMO -1  | 120   | 110  | 100  | 95   | 90  | 90  | 95  | 100 | 160 | 139 | 163 | 162 |                       |
| -2  | 125   | 90   | 84   | 94   | 90  | 90  | 85  | 99  | 138 | 143 | 136 | 160 |                       |

\* The needle on the torque wrench jumped accompanied by audible clicking indicating possible galling.

TABLE 3 - ANTI-GALLING TEST RESULTS

| TEST MATERIAL: Type 304 CRES. TEST LOADS: CYCLES 1-8 15600 lbs. CYCLES 9-12 23400 lbs. |  |      |      |      |      |      |      |     |      |      |      |      |                                      |                       |
|--|--|------|------|------|------|------|------|-----|------|------|------|------|--------------------------------------|-----------------------|
| LUBRICANT/<br>SPECIMEN   | INSTALLATION TORQUE VALUE PER TORQUING CYCLE (ft-lb) |      |      |      |      |      |      |     |      |      |      |      | NUMBER OF<br>TORQUINGS<br>TO GALLING | OTHER<br>OBSERVATIONS |
|  | 1  | 2    | 3    | 4    | 5    | 6    | 7    | 8   | 9    | 10   | 11   | 12   |                                      |                       |
| No Lubricant   | 285  | 342  | 500  | 338  |      |      |      |     |      |      |      |      | 2                                    |                       |
| N5000 -1<br>-2   | 215  | 204  | 192  | 179  | 188  | 180  | 170  | 165 | 370  | 285  | 261  | 255  | 12                                   |                       |
|  | 187  | 185  | 210  | 182  | 180  | 170  | 170  | 163 | 290  | 255  | 251  | 249  | 12                                   |                       |
| N1000 -1<br>-2   | 152  | 169  | 178  | 178  | 159  | 153  | 149  | 151 | 275  | 236  | 224  | 222  | 12                                   |                       |
|  | 179  | 155  | 158  | 160  | 160  | 157  | 155  | 156 | 263  | 262  | 240  | 266  | 12                                   |                       |
| Neolube -1<br>No. 650 -2   | 159  | 153  | 125  | 125  | 150  | 131  | 131  | 110 | 313  | 220  | 179  | 180  | 12                                   |                       |
|  | 200  | 209  | 171  | 159  | 148  | 149  | 171  | 131 | 300* | 249  | 250  | 219  | 12                                   |                       |
| NIKAL -1<br>-2   | 262  | 310* | 315* | 308* | 345* | 295* | 270* |     |      |      |      |      | 2                                    | Discontinued          |
|  | 303  | 298* | 300* | 289* | 284* | 294* |      |     |      |      |      |      | 2                                    | Discontinued          |
| N2000 -1<br>-2   | 197  | 169  | 192  | 169  | 211  | 201  | 179  | 206 | 322  | 275  | 291  | 245  | No Galling                           |                       |
|  | 232  | 182  | 182  | 172  | 202  | 194  | 195  | 191 | 339  | 269  | 253  | 268  | No Galling                           |                       |
| Never -1<br>Seez -2  | 210  | 175  | 168  | 161  | 191  | 165  | 160  | 155 | 311  | 250  | 243  | 249  | 12                                   | Gouges                |
|  | 191  | 192  | 174  | 181  | 217  | 208  | 196  | 188 | 410* | 220  | 270  | 272  | 12                                   |                       |
| NM-91 -1<br>-2   | 95   | 186  | 193  | 190  | 209  | 189  | 189  | 182 | 342  | 276  | 259  | 252  | 12                                   |                       |
|  | 228  | 190  | 190  | 183  | 218  | 218  | 191  | 180 | 313  | 269  | 348  | 346  | 12                                   |                       |
| Molykote -1<br>P37 -2  | 206  | 195  | 180  | 185  | 170  | 171  | 165  | 170 | 380* | 280  | 265  | 260  | 12                                   |                       |
|  | 167  | 154  | 150  | 141  | 162  | 161  | 167  | 165 | 285  | 275  | 263  | 285  | 12                                   |                       |
| MDSI -1<br>-2  | 219  | 270  | 255  | 222  | 178  | 178  | 182  | 190 | 319  | 418  | 460* | 345* | 8                                    |                       |
|  | 175  | 160  | 178  | 180  | 220  | 232  | 270  | 279 | 435* | 470* | 460* | 420* | 8                                    |                       |
| RLGMO -1<br>-2   | 163  | 170  | 152  | 128  | 163  | 126  | 132  | 125 | 220  | 219  | 172  | 156  | No Galling                           |                       |
|  | 139  | 122  | 121  | 122  | 123  | 118  | 117  | 112 | 211  | 175  | 180  | 170  | No Galling                           |                       |

\* The needle on the torque wrench jumped accompanied by audible clicking indicating possible galling.

TABLE 4 - ANTI-GALLING TEST RESULTS

| TEST MATERIAL: Type 304 CRES. TEST LOADS: CYCLES 1-8 15600 lbs CYCLES 9-12 23400 lbs |   |      |      |      |      |      |      |     |      |     |      |      |                       |
|--|---|------|------|------|------|------|------|-----|------|-----|------|------|-----------------------|
| LUBRICANT/<br>SPECIMEN   | BREAKAWAY TORQUE VALUE PER TORQUING CYCLE (ft-lb) |      |      |      |      |      |      |     |      |     |      |      | OTHER<br>OBSERVATIONS |
|  | 1   | 2    | 3    | 4    | 5    | 6    | 7    | 8   | 9    | 10  | 11   | 12   |                       |
| No Lubricant   | 400   | 245  | 265  | 245  |      |      |      |     |      |     |      |      |                       |
| N5000 -1<br>-2   | 140   | 155  | 150  | 135  | 135  | 130  | 120  | 120 | 275  | 220 | 190  | 180  |                       |
|  | 125   | 131  | 140  | 125  | 131  | 129  | 123  | 121 | 221  | 196 | 195  | 185  |                       |
| N1000 -1<br>-2   | 105   | 110  | 103  | 110  | 114  | 115  | 111  | 109 | 164  | 159 | 154  | 156  |                       |
|  | 121   | 109  | 100  | 98   | 106  | 112  | 112  | 102 | 178  | 181 | 167  | 166  |                       |
| Neolube -1<br>No. 650 -2   | 116   | 115  | 95   | 89   | 109  | 90   | 86   | 78  | 204  | 149 | 118  | 120  |                       |
|  | *   | *    | 130  | 123  | 100  | 102  | 120  | 99  | 300* | 190 | 190  | 162  |                       |
| NIKAL -1<br>-2   | 170   | 220* | 238* | 259* | 230* | 236* | 233* |     |      |     |      |      | Discontinued          |
|  | 209   | 265  | 262* | 250* | 211* | 231* |      |     |      |     |      |      | Discontinued          |
| N2000 -1<br>-2   | 135   | 118  | 126  | 120  | 128  | 132  | 119  | 121 | 211  | 201 | 199  | 188  |                       |
|  | 148   | 120  | 116  | 115  | 151  | 139  | 139  | 140 | 223  | 199 | 186  | 193  |                       |
| Never -1<br>Seez -2  | 159   | 135  | 123  | 120  | 140  | 129  | 122  | 119 | 249  | 199 | 184  | 186  |                       |
|  | 142   | 155  | 131  | 134  | 180  | 169  | 162  | 148 | 970* | 200 | 205  | 208  |                       |
| NM-91 -1<br>-2   | 161   | 151  | 142  | 150  | 160  | 149  | 139  | 131 | 265  | 214 | 200  | 179  |                       |
|  | 160   | 142  | 142  | 139  | 180  | 159  | 142  | 141 | 240  | 210 | 185  | 184  |                       |
| Molykote -1<br>P37 -2  | 161*  | 160  | 142  | 150  | 140  | 130  | 126  | 132 | 350* | 211 | 200  | 190  |                       |
|  | 119   | 110  | 110  | 111  | 110  | 109  | 105  | 103 | 199  | 199 | 197  | 202  |                       |
| MDSI -1<br>-2  | 162   | 200  | 160  | 139  | 135  | 111  | 100  | 99  | 219  | 275 | 298* | 330* |                       |
|  | 132   | 112  | 121  | 140  | 171  | 205  | 202  | 203 | 264  | 271 | 250* | 290* |                       |
| RLGMO -1<br>-2   | 118   | 123  | 118  | 100  | 128  | 97   | 98   | 92  | 169  | 160 | 128  | 112  |                       |
|  | 90  | 86   | 86   | 85   | 18   | 80   | 79   | 76  | 149  | 121 | 120  | 119  |                       |

\* The needle on the torque wrench jumped accompanied by audible clicking indicating possible galling.

TABLE 5 - ANTI-GALLING TEST RESULTS

| TEST MATERIAL: Alloy Steel TEST LOADS: CYCLES 1-8 23400 lbs CYCLES 9-12 35000 lbs |  |     |     |     |     |     |     |     |     |     |     |     |                                      |                       |
|---|--|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|--------------------------------------|-----------------------|
| LUBRICANT/<br>SPECIMEN  | INSTALLATION TORQUE VALUE PER TORQUING CYCLE (ft-lb) |     |     |     |     |     |     |     |     |     |     |     | NUMBER OF<br>TORQUINGS<br>TO GALLING | OTHER<br>OBSERVATIONS |
|   | 1  | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  |                                      |                       |
| No Lubricant  | *  |     |     |     |     |     |     |     |     |     |     |     | 1                                    | Seized                |
| N5000 -1<br>-2  | 250  | 228 | 221 | 216 | 221 | 213 | 210 | 213 | 333 | 365 | 380 | 389 | 12                                   |                       |
|   | 206  | 215 | 218 | 214 | 200 | 204 | 229 | 242 | 338 | 363 | 400 | 406 | 12                                   |                       |
|   | 246  | 244 | 245 | 257 | 225 | 249 | 248 | 262 | 379 | 369 | 400 | 430 | 12                                   |                       |
|   | 215  | 274 | 270 | 260 | 214 | 230 | 224 | 214 | 342 | 366 | 393 | 406 | 12                                   |                       |
| Neolube -1<br>No. 650 -2  | 159  | 148 | 149 | 148 | 136 | 130 | 136 | 136 | 214 | 230 | 260 | 251 | 12                                   | Deep Gouges           |
|   | 173  | 132 | 132 | 130 | 135 | 138 | 134 | 138 | 232 | 230 | 260 | 272 | 12                                   | Deep Gouges           |
|   | 298  | 300 | 301 | 290 | 318 | 323 | 322 | 334 | 530 | 578 | 545 | 548 | 12                                   |                       |
| NIKAL -1<br>-2  | 278  | 259 | 289 | 295 | 311 | 329 | 335 | 333 | 463 | 468 | 472 | 485 | 12                                   |                       |
|   | 209  | 252 | 233 | 228 | 232 | 244 | 238 | 243 | 319 | 331 | 310 | 298 | 12                                   |                       |
|   | 235  | 224 | 235 | 220 | 247 | 220 | 236 | 254 | 368 | 388 | 363 | 393 | 12                                   |                       |
| Never -1<br>Seez -2   | 212  | 202 | 207 | 210 | 200 | 206 | 212 | 222 | 450 | 389 | 386 | 396 | 12                                   |                       |
|   | 200  | 193 | 399 | 207 | 185 | 178 | 183 | 186 | 279 | 269 | 305 | 311 | 12                                   |                       |
|   | 227  | 223 | 208 | 201 | 230 | 219 | 208 | 205 | 388 | 391 | 357 | 351 | No Galling                           |                       |
| NM-91 -1<br>-2  | 230  | 230 | 225 | 220 | 258 | 277 | 258 | 236 | 411 | 397 | 414 | 403 | No Galling                           |                       |
|   | 202  | 199 | 199 | 199 | 214 | 233 | 202 | 202 | 398 | 353 | 349 | 349 | No Galling                           |                       |
| Molykote-1<br>P37 -2  | 225  | 235 | 204 | 219 | 218 | 211 | 225 | 213 | 369 | 355 | 380 | 350 | No Galling                           |                       |
| MDSI -1<br>-2   | 292  | 328 | 340 | 369 | 264 | 343 | 384 | 417 | 372 | 421 | 545 | 600 | 12                                   |                       |
|   | 212  | 233 | 250 | 253 | 272 | 350 | 423 | 425 | 546 | 529 | 555 | 600 | 12                                   |                       |
|   | 199  | 181 | 183 | 187 | 175 | 176 | 180 | 180 | 327 | 312 | 270 | 278 | No Galling                           |                       |
| RLGMO -1<br>-2  | 200  | 189 | 189 | 180 | 173 | 172 | 169 | 170 | 328 | 304 | 292 | 277 | 12                                   |                       |

\* The needle on the torque wrench jumped accompanied by audible clicking indicating possible galling.

TABLE 6 - ANTI-GALLING TEST RESULTS

| TEST MATERIAL: Alloy Steel TEST LOADS: CYCLES 1-8 23400 lbs CYCLES 9-12 35000 lbs |   |     |     |     |     |     |     |     |     |     |     |     |                       |
|---|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----------------------|
| LUBRICANT/<br>SPECIMEN  | BREAKAWAY TORQUE VALUE PER TORQUING CYCLE (ft-lb) |     |     |     |     |     |     |     |     |     |     |     | OTHER<br>OBSERVATIONS |
|   | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  |                       |
| No Lubricant  | *   |     |     |     |     |     |     |     |     |     |     |     | Seized                |
| N5000 -1  | 173   | 160 | 160 | 159 | 149 | 147 | 142 | 150 | 200 | 214 | 219 | 239 |                       |
| -2  | 145   | 158 | 157 | 162 | 139 | 146 | 149 | 160 | 180 | 245 | 239 | 279 |                       |
| N1000 -1  | 180   | 178 | 179 | 173 | 166 | 162 | 174 | 180 | 219 | 240 | 252 | 282 |                       |
| -2  | 160   | 190 | 200 | 200 | 154 | 168 | 173 | 168 | 220 | 244 | 269 | 248 |                       |
| Neolube -1  | 110   | 98  | 92  | 88  | 80  | 72  | 80  | 80  | 122 | 138 | 142 | 142 |                       |
| No. 650 -2  | 99  | 78  | 73  | 71  | 88  | 91  | 88  | 82  | 120 | 129 | 148 | 161 |                       |
| NIKAL -1  | 212   | 190 | 209 | 201 | 215 | 206 | 222 | 221 | 415 | 405 | 400 | 385 |                       |
| -2  | 218   | 178 | 197 | 202 | 222 | 240 | 254 | 234 | 290 | 308 | 339 | 309 |                       |
| N2000 -1  | 151   | 162 | 178 | 168 | 152 | 157 | 162 | 182 | 193 | 204 | 220 | 205 |                       |
| -2  | 160   | 165 | 178 | 170 | 165 | 160 | 160 | 168 | 246 | 253 | 260 | 263 |                       |
| Never -1  | 150   | 148 | 150 | 155 | 140 | 151 | 156 | 167 | 321 | 261 | 289 | 271 |                       |
| Seez -2   | 140   | 141 | 140 | 150 | 124 | 122 | 131 | 134 | 191 | 182 | 181 | 188 |                       |
| NM-91 -1  | 162   | 160 | 149 | 144 | 163 | 151 | 149 | 148 | 248 | 242 | 241 | 240 |                       |
| -2  | 165   | 171 | 162 | 150 | 179 | 188 | 180 | 175 | 270 | 265 | 270 | 260 |                       |
| Molykote -1   | 139   | 136 | 135 | 142 | 155 | 141 | 148 | 145 | 237 | 218 | 215 | 212 |                       |
| P37 -2  | 149   | 151 | 142 | 148 | 154 | 150 | 140 | 141 | 242 | 230 | 234 | 230 |                       |
| MDSI -1   | 192   | 198 | 210 | 200 | 160 | 160 | 212 | 232 | 254 | 300 | 385 | 458 |                       |
| -2  | 161   | 171 | 180 | 189 | 202 | 245 | 281 | 295 | 365 | 410 | 405 | 430 |                       |
| RLGMO -1  | 141   | 133 | 135 | 131 | 125 | 122 | 122 | 122 | 205 | 209 | 199 | 200 |                       |
| -2  | 141   | 139 | 131 | 119 | 122 | 118 | 118 | 113 | 205 | 194 | 190 | 192 |                       |

\* The needle on the torque wrench jumped accompanied by audible clicking indicating possible galling.